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(54) Title: METHOD FOR DETERMINING FEED QUALITY

(57) Abstract

A method for determining a biomechanical property of a feed, the method comprising the steps of: (a) subjecting the feed to infrared radiation to obtain spectral data; and (b) using the spectral data to determine the biomechanical property; whereby, the biomechanical property of the feed is determined on the basis of the bond energies of the chemical constituents of the feed.

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Method for Determining Feed Quality

This invention relates to a method for quantifying biomechanical properties of animal feed based on a correlation between the chemical and biomechanical properties of the feed, and to methods for objectively measuring the quality of animal feed, such as fodders including hay, pastures and forages.

Diet is the major determinant of productivity of an animal. In the livestock industry, animals are farmed for meat, wool and other valuable products. The diet of farmed livestock is largely dictated by man and, given the effect of diet on animal production, it is highly desirable to optimise the diet of livestock to gain maximum benefit from the natural resource.

Feed quality is one variable that has a major impact on animal productivity. In this respect, feed quality affects the amount of feed an animal will consume and the feeding value it gains from the feed consumed. In the case of cattle, sheep and other ruminants, feed quality depends on digestibility, chemical attributes (nutrient composition) and biomechanical attributes (namely how easy it is for an animal to chew the feed during ingestion and rumination).

It is generally accepted that there are constraints on the intake of feed by ruminant animals, that the amount of useful energy obtained by a ruminant animal may fall short of the amount that the animal can potentially use, and that this would result in reduced productivity. For example, the principal constraints to voluntary intake of fodders are resistance of fodder fibre to chewing and digestibility (provided that the intake is not otherwise constrained by low palatability, deleterious secondary compounds, or the inadequacy of essential nutrients). Differences between feeds, such as fodders, in their resistance to chewing are reflected in differences in biomechanical properties, including comminution energy, shear energy, compression energy, tensile strength, shear strength and intrinsic shear strength.

Hay is a common feed, and its quality is significantly affected by factors such as seasonal differences, haymaking practices and pasture composition. It has been shown in one recent survey that in some years as little as 11% of hay produced was good enough to promote liveweight gain in weaner sheep. This possibility of wide variation in measures of hay quality is a matter of increasing concern, and has given rise to a demand for a method of objective quality assessment.

A hay quality system adopted in the United States of America uses a measure known as relative feed value (RFV) to distinguish between hays of different quality. The RFV is calculated from the dry matter digestibility, which is predicted from acid detergent fibre (ADF) content, and from the dry matter intake, which is predicted from neutral detergent fibre (NDF) content.

The RFV based system suffers from a number of disadvantages. For example, the ADF and NDF contents of fodders are determined by chemical methods which take several days to complete, and thus are expensive in terms of resources.

While objective quality assessment and product specification has become an integral part of the production and marketing in domestic and export markets for the Australian grain, wool, meat and dairy industries, performance-based quality standards are not presently in place for feeds such as hays and other fodders. Consequently;

(a) the feed buyer cannot be sure of getting value for money, and this is likely to become increasingly important in respect of export markets if other exporting countries are able to guarantee standards for their product;

(b) the feed producer cannot be sure of getting a higher price for a superior product;

(c) livestock producers are unable to objectively formulate rations or supplementary feeding regimes to achieve animal production targets; and

(d) the market for animal feed tends to be unstable.

Whilst the relationship between biomechanical properties of feed and feed quality is now accepted, there is a need for a convenient, inexpensive and relatively accurate assay method for feed to determine its quality. An accurate determination of feed quality allows for optimisation of feeding regimes and improved animal production for obvious economic gains.

It is an object of this invention to overcome or at least partially alleviate the aforementioned problems and/or reduce the uncertainties and concomitant problems of the prior art systems for measuring the biomechanical properties of feed and hence determining feed quality.

Thus, the present invention provides a method for determining a biomechanical property of a feed, the method comprising the steps of;

(a) subjecting the feed to infrared radiation to obtain spectral data; and

(b) using the spectral data to determine the biomechanical property;

whereby the biomechanical property of the feed is determined on the basis of the bond energies of the chemical constituents of the feed.

The spectral data may be used directly to determine the biomechanical property of the feed. Alternatively, the spectral data may be used to determine another property of the feed and the other property is used to determine the biomechanical property on the basis of a correlation between the other property and the biomechanical property.

When the biomechanical property is determined via another property, the other property is preferably a chemical property of the feed such as the ADF content or the NDF content or the lignin content.

There is a variety of biomechanical properties of the feed that may be determined. Preferably, the biomechanical properties are selected from the group comprising shear energy, compression energy, comminution energy, tensile strength, shear strength and intrinsic shear strength.

The spectral data may comprise a reflectance spectrum at a combination of wavelengths or over a predetermined range of wavelengths such as 700nm-3000nm, or more preferably 1100nm-2500nm. Preferably, the data obtained for the spectral range of 1850nm-1970nm is disregarded, this being the range over which water reflects strongly.

The spectral data may be recorded at one or more wavelength intervals throughout the spectral range. When the spectral data is a reflectance spectrum over a predetermined range it is preferably measured at 2nm intervals over the range. Of course, if so desired the spectral data may be measured at intervals other than 2nm.

When the spectral data is used to directly determine a biomechanical property, the biomechanical property is preferably determined by comparison of the spectral data with a calibration equation that reflects the relationship between reflectance and the biomechanical property. Preferably, the calibration curve is determined on the basis of laboratory data establishing a correlation between reflectance and the biomechanical property.

Thus, the present invention also provides a method for determining a biomechanical property of a feed, the method comprising the steps of;

(a) subjecting the feed to infrared radiation to obtain spectral data; and

(b) comparing the spectral data obtained in (a) with a calibration equation to determine the biomechanical property;

whereby the biomechanical property of the feed is determined on the basis of the bond energies of the chemical constituents of the feed.

The present invention also provides a method for determining feed quality, the method comprising the steps of;

(a) subjecting the feed to infrared radiation to obtain spectral data;

(b) using the spectral data to determine a biomechanical property of the feed; and

(c) using the value of the biomechanical property obtained in step (b) to determine feed quality;

whereby the biomechanical property of the feed and thus the feed quality is determined on the basis of the bond energies of the chemical constituents of the feed.

In one particular form, the method described immediately above may further comprise the determination of an additional property of the feed. The additional property may vary and preferably is selected from the group comprising the digestibility of the feed *in vivo* or *in vitro*, the ADF content or the NDF content, or the lignin content.

The present invention is based on research establishing a strong correlation between the bond energies as they relate to the physical structure, and the biomechanical properties of feed. Once this correlation is established the bond energies of the chemical constituents, and in turn the biomechanical properties of the feed, can be determined using infrared spectroscopy. The biomechanical

properties quantified in this way are useful for accurately determining feed quality.

In this respect, research resulting in the present invention has shown that the biomechanical attributes of feeds such as cereal and legume hays, straws, and mature, dry subterranean clovers are much more strongly related to animal performance than are digestibility or chemical composition of the feeds.

Thus, comminution energy, the energy required to grind or comminute fodder material, has proved to be a very effective indicator of forage consumption constraint (FCC), which is the difference between the quantity of forage an animal should consume to satisfy its capacity to use energy (a theoretical maximum) and the actual voluntary dry matter intake achieved.

Shear energy, the energy required to shear fodder material, and compression energy, the energy required to compress fodder material, are two biomechanical feed characters of fodders that are closely related to comminution energy and which also are good predictors of FCC.

In this respect, feed quality can be assessed in a number of ways. The forage consumption constraint (FCC) is one convenient measure of feed quality and equates to the difference between the quantity of the fodder that the animal would be attempting to consume to satisfy its capacity to use energy (theoretical maximum intake) and the voluntary forage consumption (VFC).

Thus, the present invention also provides a method for determining feed quality, the method comprising the steps of;

(a) subjecting the feed to infrared radiation to obtain spectral data;

(b) using the spectral data to determine a biomechanical property of the feed; and

(c) using the value of the biomechanical property obtained in step (b) to determine the forage consumption constraint (FCC) or voluntary feed consumption (VFC) as a measure of feed quality;

whereby the biomechanical property of the feed and thus the feed quality is determined on the basis of the bond energies of the chemical constituents of the feed.

The present invention is based on the finding that variations in biomechanical properties such as shear energy, comminution energy and compression energy are reflected in NIR spectra of fodders. This finding, together with recognition of the value of biomechanical characters for the prediction of FCC (and, in turn, the prediction of voluntary feed consumption (VFC)) makes it possible for quicker, less expensive, more convenient and more reliable prediction of feed quality than hitherto known and predicted.

Accordingly, this invention provides a method of (i) assessing the suitability of a fodder, such as a forage, to meet a required animal performance; or (ii) predicting the VFC of a forage; or (iii) predicting the FCC of a forage, which method comprises subjecting a sample of the forage to NIR radiation and determining the reflectance at selected wavelengths.

It has been found that the biomechanical properties, such as shear and comminution energy values for a given fodder, correlate with the fodder's reflectance of infrared radiation. More specifically, the invention is based on research showing that:

(a) NIR wavelengths at which reflectance (R), namely the second derivative of the logarithm of the inverse of R, correlates significantly with the variation in energy required to shear fodder materials are 1168nm, 1458nm, 1598nm, 1718nm, 1828nm and 2048nm. For the prediction of fodder shear energy (y_1, $kJ.m^{-2}$) the following equation may be used:

$$y_1 = 19.95 + 10239.46\, R_{1168} + 3623.49\, R_{1458} - 4255.61\, R_{1598} - 5319.88\, R_{1718} + 5148.38\, R_{1828} + 2452.05\, R_{2048}$$

(b) NIR wavelengths at which the second derivative of the logarithm of the inverse of reflectance (R) correlates significantly with the variation in energy required to comminute fodder materials are 1138nm, 2018nm, 2128nm and 2408nm.

For the prediction of fodder comminute energy (y_2, kJ.kg DM^{-1}) the following equation is proposed:

$$y_2 = 231.42 + 18224.74\, R_{1138} - 4955.12\, R_{2018} - 3005.37\, R_{2128} + 4290.18\, R_{2408}$$

(c) NIR wavelengths at which the second derivative of the logarithm of the inverse of reflectance (R) correlates significantly with the variation in compression energy are 1268nm, 1588nm, 1728nm, 2278nm. For the prediction of compression energy (y_3, kJ.kgDM^{-1}) the following equation may be used:

$$y_3 = -0.71 - 911.04\, R_{1268} + 112.57\, R_{1588} - 79.48\, R_{1728} - 28.02\, R_{2278}$$

(d) NIR wavelengths at which the second derivative of the logarithm of the inverse of reflectance (R) correlates significantly with variation in *in vivo* digestibility of dry matter (DMD) (y_4, %) is 1158nm, 1238nm, 1668nm, 1908nm, 1918nm, and 2248nm. For prediction of the DMD (y_4, %) of a fodder the following equation is proposed:

$$y_4 = 46.62 + 8162.72\, R_{1158} - 8799.69\, R_{1238} + 1249.01\, R_{1668} + 519.46\, R_{1908} - 367.08\, R_{1918} - 161.84\, R_{2248}$$

(e) NIR wavelength at which the second derivative of the logarithm of the inverse of reflectance (R) correlates significantly with variation in *in vitro*

digestibility of dry matter (IVDMD) is 1698nm, 1748nm, 1908nm, 1918nm and 2158nm. For prediction of the DMD (*in vitro*) of a fodder the following equation is proposed:

$$y_5 = 63.43 - 2186.89\ R_{1698} - 1491.99\ R_{1748} + 981.30\ R_{1908} - 556.01\ R_{1918} + 2003.05\ R_{2158}$$

Accordingly, in a preferred method according to this invention, the infrared wavelengths at which reflectance is measured comprise one or more of the following: 1168nm, 1458nm, 1598nm, 1718nm, 1828nm, 2048nm, 1138nm, 2018nm, 2128nm, 2408nm, 1268nm, 1588nm, 1728nm, 2278nm, 1158nm, 1238nm, 1668nm, 1908nm, 2248nm, 1698nm, 1748nm, 1918nm and 2158nm.

It will be understood that the foregoing are wavelengths at which the strongest correlations have been observed, and the possibility of useful correlations being observed at other wavelengths are highly likely.

Essentially, it can be shown that in the same way that a decrease in comminution energy is reflected by a decrease in forage consumption constraint, there is also a linear relationship between comminution energy or shear energy and the consumption constraint of a fodder. Thus, the use of NIR spectra, in conjunction with the equations detailed at paragraphs (a) to (e) above, permits estimation of the VFC of a fodder, which together with estimates of digestibility (conveniently obtained from NIR spectra) can be expected to provide a valuable basis for performance-based quality standards for fodders.

It is to be appreciated that the intention of this invention is to offer a quick, reliable and relatively inexpensive means of obtaining information from which the fodder producer and user, such as purchaser, might make informed judgements about the market value of a given fodder sample relative to alternatives, and of its suitability for a particular purpose.

Conceivably, fodder quality predictions obtained by the method of this invention could be a useful component of, or used in conjunction with, for example, Decision Support Software (DSS) packages designed to assist livestock management.

It is further envisaged that by combining NIR measurements made by a remote sensing system, such as Landsat, with data from a Geographical Information System, the invention will provide a means of making reliable predictions of pasture quality. These predictions, together with predictions of feed intake and animal performance, should then provide a useful basis for strategies of supplementary feeding to improve performance in grazing ruminants.

The present invention also provides for a spectrometer configured to determine biomechanical properties and/or quality of feed according to the methods of the present invention. Preferably, the spectrometer includes a data processing means which enables the spectrometer to receive a feed sample and quantify either or both the biomechanical properties of the feed and the quality of the feed. In one particular form the data processing means includes a calibration equation to facilitate the determination of the feed quality or biomechanical property.

The invention will now be described with reference to the following examples. The description of the examples is in no way to limit the generality of the preceding paragraphs.

EXAMPLES

The energy of molecular vibrations correspond to the energy of the infrared spectrum of the electromagnetic spectrum, and these molecular vibrations may be detected and measured in the wavelength range of the infrared spectrum. Functional groups in molecules have vibration frequencies that are characteristic of that functional group and that are within well-defined regions of the infrared spectrum.

For organic compounds the principal analytical features of the near infrared (NIR) spectrum are due to absorbance of radiant energy by bonds between hydrogen, carbon, nitrogen, oxygen or with sulphur, phosphorus and metal halides. When organic compounds are irradiated with infrared radiation at wavelengths between 700 and 3000nm part of the incident radiation is absorbed and the remainder is reflected, refracted or transmitted by the sample. Most quantitative reflectance analyses are made in the wavelength range of 1100 to 2600nm. The amount of energy absorbed or diffusely reflected at any given wavelength in this wavelength range is related to the chemical composition of the organic compound. NIR spectroscopy uses detectors to measure the amount of radiation that is diffusely reflected by the irradiated sample.

NIR spectroscopic analysis is an analytical procedure calibrated to a primary reference method. Calibration in NIR spectroscopy (NIRS) relies on similarities among the spectra, and analytical properties of interest in the reference samples. In this example the analytical properties of interest were the biomechanical characters of forages, and the procedure that was adopted in this example was as follows:

a) prediction of biomechanical characters of a range of grasses using NIR spectroscopy was established by developing a calibration equation(s) from laboratory determined values of a set of reference samples.

b) validation of the equation(s) either by using laboratory determined values of a separate set of samples, or by a cross-validation procedure using the laboratory determined values of the reference samples.

c) using the NIRS-predicted values for biomechanical characters of the forages and for digestibility of the forages, forage consumption constraint (FCC) was predicted, and in turn voluntary feed consumption (VFC) was predicted.

d) the predicted FCC and VFC were compared with actual data from groups of animals fed each of these forages.

Example A: Developing a calibration equation to predict biomechanical properties of herbage:

The samples used in this example were a range of varieties of *Panicum spp.* harvested at a range of plant maturities throughout the growing season (Table 1). Each of the samples was dried and chaffed, and then fed to groups of sheep (8 sheep per group) which were penned individually, to determine *in vivo* dry matter digestibility (DMD), VFC and FCC. Samples of the hays were stored for laboratory analyses.

Biomechanical properties of the forages were determined using published methods; the energies required to shear or compress the forages according to Baker, Klein, de Boer and Purser (Genotypes of dry, mature subterranean clover differ in shear energy. Proceedings of the XVII International Grassland Congress 1993. pp 592-593.) and the energy required to comminute the forages according to Weston and Davis (The significance of four forage characters as constraints to voluntary intake. Proceedings of the Third International Symposium on the Nutrition of Herbivores, Penang, 1991). *In vitro* digestibility of dry matter (IVDMD) was determined by the pepsin-cellulase technique as modified by Klein and Baker (Composition of the fractions of dry, mature subterranean clover digested *in vivo* and *in vitro*. Proceedings of the XVII International Grassland Congress 1993. pp593-595.).

There are several ways to process samples for NIRS analysis. and in this example the samples were ground through a cyclone mill with a 1 mm screen and equilibrated at 25^{0}C for at least 24h before NIRS analysis. The samples were scanned by a monochromating near infrared reflectance spectrophotometer (Perstorp NIRS 6500) and the absorption spectra recorded for the range 1100 to 2500nm at 2nm intervals. The spectral range 1850 to 1970nm, where water absorbs strongly, was disregarded in further analysis of the spectral data.

For NIRS analysis the samples were divided into two groups: one group to be used as a 'calibration' set to establish a prediction equation, and a second group, the 'validation' set, to be used to validate the prediction equation. There are a number of ways to select the samples for each set. In this example the samples were ranked according to each of the characters that were to be predicted and every other sample was selected for the calibration set (33 samples) and the validation set (32 samples). Thus, for each character that was evaluated, a different selection was made from the 65 samples to establish the respective calibration and validation sample sets.

The ranges, mean, median and variation in the laboratory-determined values for each of the characters of interest in the calibration and validation sets are listed in Table 2.

The software for scanning, mathematical processing and statistical analysis were supplied with the spectrophotometer by the manufacturers. The spectral data were transformed by taking the second derivative of the logarithm of the inverse of the reflectance (R) at each wavelength (d" log (1/R)). The similarities amongst the spectra (Figure 1) of the samples in the validation and calibration sets were determined using principal components scores to rank the spectra according to the Mahalanobis distance from the average of the spectra. The Mahalanobis distance values were standardized by dividing them by their average value, and were denoted 'global' H values (Table 3).

Calibration equations were developed using the calibration samples by regressing the data from the laboratory analyses of each biomechanical property against the corresponding transformed spectral data using the following mathematical methods:

a) Stepwise linear regression
b) Step-up linear regression
c) Principal components regression (PCR)
d) Partial least squares regression (PLS), and
e) Modified partial least squares regression (MPLS).

Stepwise calibrations were developed for each calibration set of samples using the mathematical treatments of the spectral data 2,2,2; 2,5,5; 2,10,5; and 2,10,10; where the first number denotes that the second derivative was used, the second indicates that second derivatives of the spectral data (determined at 2nm intervals) were taken at intervals of 4, 10 or 20nm, and the third indicates that the function was smoothed using the 'boxcar' method over intervals of wavelength of 4, 10, or 20nm (Table 4a). Likewise step-up calibrations were developed for each calibration set with up to 6 terms in each calibration equation using mathematical treatments 2,2,2; 2,5,5; 2,10,5; and 2,10,10 (Table 4b). Calibrations developed for each calibration set using principal components regression, partial least squares regression, or modified partial least squares regression each were developed using mathematical treatments 2,5,5 and 2,10,10 (Table 4c).

In developing the calibration equations in the stepwise and step-up regressions, only wavelengths with partial F-statistic of more than 8 were accepted for the models.

For each calibration using each calibration set the following calibration statistics were determined:

a) Squared multiple correlation coefficient (R^2), an indication of the proportion of the variation in the calibration set that is adequately modelled by the calibration equation.

b) The standard error of calibration (SEC) together with its confidence interval (± CL), which is the standard deviation for the residuals due to difference between the laboratory determined (reference) and the NIR predicted values for samples within the calibration set

Once the calibration equations were developed, each equation was validated by using it to predict the respective biomechanical property values for each sample in the validation sample set. For each calibration equation the following validation statistics were determined:

a) Simple linear correlation coefficient (r^2) between the laboratory determined and NIR predicted values.

b) The bias (or systematic error) in the regression relationship between the laboratory determined (reference) and NIR predicted values.

c) The confidence limits of the bias in the regression relationship between the laboratory determined (reference) and NIR predicted values.

d) The standard error of prediction, corrected for bias (SEP(C)), which represents the unexplained error of the prediction, the deviation of the differences between laboratory determined and NIR predicted values.

e) The coefficient of determination, or slope (β), and y-intercept (α) of the linear regression relationship between the laboratory determined and NIR predicted values.

f) The residual standard deviation (RSD) of the linear regression relationship between the laboratory determined and NIR predicted values.

In addition, the calibration equations were validated using a procedures of cross-validation. These are procedures where every sample in the calibration set was used once for prediction, and the standard error of validation corrected for bias (SEV(C), for stepwise and step-up regressions) and cross-validation (SECV, for multivariate regressions) can be determined.

Calibration equations for each biomechanical character were selected using the following criteria:

a) Lowest partial F-ratio, highest R^2, lowest SEC and, for PCR, PLS and MPLS, lowest SEV(C) (or, for multivariate regressions, SECV)

b) Highest r^2, lowest bias and $|bias|$ < bias confidence limit, lowest SEP(C), β closest to 1.0, α closest to 0, and lowest RSD. As well, SEP(C) was compared with the standard error of laboratory determined values amongst all 65 samples, listed in Table 5.

Calibration equations were similarly established to predict *in vivo* digestibility and *in vitro* digestibility. The coefficients for each wavelength in the selected calibration equations from stepwise or step-up regression analyses are listed in Table 6a, and those from multivariate analyses are listed in Table 6b.

Simple linear correlation coefficient (r^2) between the laboratory determined and NIR predicted values for each of the biomechanical characters (energies required to shear, comminute or compress) and digestibility of dry matter determined *in vivo* or *in vitro* of the samples in the validation set are shown in Figures 2a, 2b, and 2c. The NIR predicted values are predicted using calibration equations that best met the criteria listed above.

Example B: Prediction of FCC and VFC using NIR determinations of energy required to shear and *in vivo* digestibility:

To demonstrate the prediction of voluntary feed consumption using NIR determined values for a biomechanical character and digestibility of forages, samples of *Panicum spp*. hay were selected which were common to both of the validation sample sets used to establish the NIR prediction equations for energy required to shear and *in vivo* digestibility. The hays represented the range of varieties in the sample set, and are listed in Table 7. The samples were scanned by the same spectrophotometer that was used to establish the

calibration equations, and the absorption spectra were recorded in the range 1100 to 2500nm at 2nm intervals. Values for energy required to shear and *in vivo* digestibility were predicted from calibration equations (Tables 4a, 4b and 4c) using the recorded spectral data.

These values then were used to estimate FCC from the relationship between biomechanical character(s) and FCC of the range of forages used by Weston and Davis (1991). Energy required to shear the forages used by Weston and Davis was determined according to Baker *et al.* (1993). The relationship between the energy required to shear these forages (kJ/m^2) and FCC (g organic matter (OM) / d / kg metabolic body weight (MBW)) was described by the relationship:

Energy required to shear (x) = -26.13 + 5.53 (FCC (y))

where R = 0.92; RSD = 8.70; N = 13; P < 0.0001.

FCC from this relationship and *in vivo* digestibility predicted by NIR were then used to estimate VFC, as the difference between the animal's capacity to use energy (as defined by Weston and Davis, 1991) and FCC. These data are summarised in Table 8.

VFC predicted in this way explained most of the variation in actual VFC (R = 0.87; RSD = 5.04; P = 0.023) (Figure 3).

Table 1. Description of herbage used in this example.

Genus	Species	Variety	Common name	Part of plant	Process undergone	Stage of maturity	Regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	late bloom (9 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	late bloom (13 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	late bloom (4 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	mid bloom (1 month's regrowth)	mid bloom - regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	mid bloom (1 month's regrowth)	mid bloom - regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	mid bloom (10 weeks' regrowth)	mid bloom - regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	mid bloom (6 weeks' regrowth)	mid bloom - regrowth
Panicum	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	vegetative regrowth (29 days')	vegetative regrowth
Panicum	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	late bloom	late bloom
Panicum	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	late bloom (4 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	late bloom (19 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	late bloom (14 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	mid bloom (9 weeks' regrowth)	mid bloom - regrowth
Panicum	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	mid bloom (6 weeks' regrowth)	mid bloom - regrowth
Panicum	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	vegetative regrowth (28 days')	vegetative regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	early bloom (1 month's regrowth)	early bloom - regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	late bloom (14 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	late bloom (4 weeks' regrowth)	late bloom - regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	mid bloom (6 weeks' regrowth)	mid bloom - regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	mid bloom (10 weeks' regrowth)	mid bloom - regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	vegetative regrowth (31 days')	vegetative regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	mid bloom (1 month's regrowth)	mid bloom - regrowth
Panicum	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	mid bloom (4 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	late bloom (4 weeks' regrowth)	late bloom - regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	mid bloom (13 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	mid bloom (10 weeks' regrowth)	mid bloom - regrowth

Table 1. Description of herbage used in this example.
(cont'd)

Genus	Species	Variety	Common name	Part of plant	Process undergone	Stage of maturity	Regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	vegetative regrowth (4 weeks')	vegetative regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	vegetative regrowth (33 days')	vegetative regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	vegetative regrowth (28 days')	vegetative regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	vegetative regrowth (1 month's)	vegetative regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	vegetative regrowth (1 month's)	vegetative regrowth
Panicum	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	vegetative regrowth (6 weeks')	vegetative regrowth
Panicum	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	early bloom (1 month's regrowth)	early bloom - regrowth
Panicum	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	early bloom (10 weeks' regrowth)	early bloom - regrowth
Panicum	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	late bloom (4 weeks' regrowth)	late bloom - regrowth
Panicum	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	mid bloom (13 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum*	Hamil	Guinea grass	leaf	dried and chaffed	54 days' regrowth	regrowth
Panicum	*maximum*	Hamil	Guinea grass	leaf	dried and chaffed	75 days' regrowth	regrowth
Panicum	*maximum*	Hamil	Guinea grass	leaf	dried and chaffed	68 days' regrowth	regrowth
Panicum	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	vegetative (6 weeks' regrowth)	vegetative
Panicum	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	vegetative regrowth (9 weeks')	vegetative regrowth
Panicum	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	vegetative regrowth (32 days')	vegetative regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	late bloom (6 weeks' regrowth)	late bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (1 month's regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (10 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (14 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (4 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (15 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (9 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (1 month's)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (13 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (4 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (11 weeks' regrowth)	mid bloom - regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	vegetative regrowth (28 days')	vegetative regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	vegetative regrowth (32 days')	vegetative regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	vegetative regrowth (4 weeks')	vegetative regrowth
Panicum	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	vegetative regrowth (4 weeks')	vegetative regrowth

Table 2. Summary statistics for each calibration and validation set

	Energy required to shear (kJ/m²)	Energy required to comminute (kJ/kg DM)	Energy required to compress (kJ/kg DM)	Digestibility of dry matter *in vivo* (%)	Digestibility of dry matter *in vitro* (%)
Energy required to shear					
Calibration set					
mean	15.48	134.9	3.70	55.7	53.3
median	15.17	133.8	3.65	56.0	55.1
maximum	20.95	216.5	4.39	64.0	63.0
minimum	10.80	72.5	3.25	43.0	39.8
standard deviation	2.572	37.50	0.265	5.73	6.97
Validation set					
mean	15.43	130.9	3.78	55.6	52.7
median	15.20	128.3	3.75	56.5	53.3
maximum	20.43	205.2	4.24	64.0	63.0
minimum	10.94	54.5	3.34	47.0	40.1
standard deviation	2.444	37.50	0.229	5.36	7.01
Energy required to comminute					
Calibration set					
mean	15.01	133.1	3.69	55.7	52.8
median	14.76	129.5	3.70	57.0	54.7
maximum	19.97	216.5	4.18	64.0	63.0
minimum	10.80	54.5	3.25	43.0	39.8
standard deviation	2.444	38.82	0.227	5.64	7.06
Validation set					
mean	15.92	132.9	3.79	55.6	53.2
median	15.97	130.2	3.79	55.5	54.7
maximum	20.95	205.2	4.39	64.0	62.5
minimum	11.46	60.7	3.34	47.0	40.9
standard deviation	2.490	36.20	0.263	5.47	6.92
Energy required to compress					
Calibration set					
mean	15.28	128.1	3.74	56.3	53.8
median	15.07	128.4	3.72	57.0	54.7
maximum	19.97	204.0	4.39	64.0	63.0
minimum	10.80	54.5	3.25	47.0	39.8
standard deviation	2.477	38.00	0.261	5.15	6.64
Validation set					
mean	15.64	138.0	3.74	55.0	52.2
median	15.42	132.5	3.72	54.5	54.5
maximum	20.95	216.5	4.24	64.0	62.0
minimum	11.46	60.7	3.34	43.0	40.1
standard deviation	2.530	36.39	0.240	5.87	7.26
Digestibility of dry matter *in vivo*					
Calibration set					
mean	15.14	133.9	3.74	55.5	53.1
median	15.17	128.4	3.72	56.0	55.1
maximum	20.95	216.5	4.24	64.0	63.0
minimum	10.80	60.7	3.25	43.0	40.1
standard deviation	2.528	36.39	0.247	5.73	7.33
Validation set					
mean	15.78	132.1	3.75	55.7	52.9
median	15.20	134.7	3.72	56.5	54.4
maximum	20.37	205.2	4.39	64.0	63.0
minimum	10.94	54.5	3.34	47.0	39.8
standard deviation	2.446	38.70	0.255	5.36	6.63

Table 2 (cont'd). Summary statistics for each calibration and validation set

	Energy required to shear (kJ/m²)	Energy required to comminute (kJ/kg DM)	Energy required to compress (kJ/kg DM)	Digestibility of dry matter *in vivo* (%)	Digestibility of dry matter *in vitro* (%)
		Digestibility of dry matter *in vitro*			
Calibration set					
mean	14.70	131.3	3.75	55.6	53.0
median	14.34	129.3	3.71	56.0	54.7
maximum	19.36	216.5	4.39	64.0	63.0
minimum	10.80	54.5	3.25	43.0	40.1
standard deviation	2.235	42.58	0.241	5.78	6.94
Validation set					
mean	16.19	134.6	3.74	55.6	53.0
median	16.16	133.8	3.74	56.0	54.7
maximum	20.95	194.8	4.24	64.0	63.0
minimum	10.94	65.7	3.34	47.0	39.8
standard deviation	2.538	31.84	0.260	5.33	7.05

Table 3. Mahalanobis distances

	Mean	Median	Range
For full sample set:	0.655	0.623	0.203 - 1.983
For calibration sets for:			
Energy required to shear	0.588	0.549	0.171 - 1.646
Energy required to comminute	0.718	0.676	0.350 - 1.553
Energy required to compress	0.757	0.760	0.188 - 1.440
Digestibility of dry matter *in vivo*	0.673	0.634	0.389 - 1.547
Digestibility of dry matter *in vitro*	0.645	0.574	0.185 - 1.178

Table 4a. Calibration and validation statistics

Energy required to shear				
	Stepwis. Regression			
	2,2,2	2,5,5	2,10,5	2,10,10
Lowest partial F-ratio	10.27	6.18	8.27	4.70
R^2	0.798	0.787	0.795	0.780
SEC	1.155	1.188	1.166	1.207
SEC CL	1.493	1.535	1.507	1.560
SEV(C)	1.230	1.306	1.273	1.322
r^2	0.368	0.625	0.520	0.495
Bias	0.690	0.710	0.700	0.720
Bias CL	1.484	1.527	1.498	1.551
SEP (C)	1.500	1.540	1.520	1.570
Slope	0.604	0.617	0.598	0.758
Intercept	6.340	5.440	5.640	3.710
R.S.D.	1.627	1.627	1.484	1.476
|Bias| - Bias CL	-0.794	-0.817	-0.798	-0.831
|Bias| < Bias CL?	Yes	Yes	Yes	Yes
number of terms	*6*	*5*	*5*	*6*
Energy required to comminute				
	Stepwise Regression			
	2,2,2	2,5,5	2,10,5	2,10,10
Lowest partial F-ratio	5.54	4.45	16.55	10.89
R^2	0.910	0.802	0.818	0.831
SEC	11.626	17.281	16.546	15.980
SEC CL	1.493	1.535	1.507	1.560
SEV(C)	13.103	18.040	17.587	17.100
r^2	0.363	0.429	0.374	0.213
Bias	6.980	10.370	9.930	9.590
Bias CL	14.941	22.209	21.264	20.537
SEP (C)	15.110	22.460	21.510	20.770
Slope	0.530	0.575	0.607	0.417
Intercept	58.300	48.900	48.600	74.600
R.S.D.	28.900	27.360	28.650	32.120
|Bias| - Bias CL	-7.961	-11.839	-11.334	-10.947
|Bias| < Bias CL?	Yes	Yes	Yes	Yes
number of terms	*6*	*3*	*4*	*4*
Energy required to compress				
	Stepwise Regression			
	2,2,2	2,5,5	2,10,5	2,10,10
Lowest partial F-ratio	5.05	4.44	7.90	16.19
R^2	0.784	0.500	0.525	0.534
SEC	0.121	0.209	0.204	0.202
SEC CL	1.493	1.535	1.507	1.560
SEV(C)	0.135	0.224	0.217	0.215
r^2	0.069	0.113	0.008	0.067
Bias	0.070	0.130	0.120	0.120
Bias CL	0.156	0.269	0.262	0.260
SEP (C)	0.160	0.270	0.270	0.260
Slope	0.180	-0.080	0.314	0.211
Intercept	3.060	4.030	2.580	2.960
R.S.D.	0.229	0.229	0.227	0.232
|Bias| - Bias CL	-0.086	-0.139	-0.142	-0.140
|Bias| < Bias CL?	Yes	Yes	Yes	Yes
number of terms	*6*	*4*	*4*	*4*

Table 4a (cont'd)

Digestibility of dry matter *in vivo*				
	Stepwis Regression			
	2,2,2	2,5,5	2,10,5	2,10,10
Lowest partial F-ratio	7.63	20.68	4.28	6.08
R^2	0.934	0.917	0.914	0.921
SEC	1.107	1.236	1.258	1.207
SEC CL	1.493	1.535	1.507	1.560
SEV(C)	1.215	1.368	1.341	1.284
r^2	0.654	0.881	0.878	0.876
Bias	1.070	0.890	0.910	0.900
Bias CL	0.156	0.269	0.262	0.260
SEP (C)	2.320	1.940	1.980	1.960
Slope	0.705	0.878	0.840	0.827
Intercept	16.500	6.690	8.640	9.340
R.S.D.	3.153	1.852	1.873	1.888
|Bias| - Bias CL	0.914	0.621	0.648	0.640
|Bias| < Bias CL?	No	No	No	No
number of terms	*6*	*6*	*6*	*5*
Digestibility of dry matter *in vitro*				
	Stepwise Regression			
	2,2,2,1	2,5,5	2,10,5	2,10,10
Lowest partial F-ratio	7.68	11.84	4.33	6.31
R^2	0.935	0.933	0.915	0.922
SEC	1.808	1.751	2.052	1.974
SEC CL	1.493	1.535	1.507	1.560
SEV(C)	1.984	1.981	2.186	2.100
r^2	0.699	0.847	0.743	0.736
Bias	1.080	1.050	1.230	1.180
Bias CL	2.324	2.250	2.637	2.537
SEP (C)	2.340	2.280	2.670	2.570
Slope	0.839	0.962	0.775	0.763
Intercept	8.790	1.650	12.200	12.700
R.S.D.	3.805	3.794	3.805	2.719
|Bias| - Bias CL	-1.244	-1.200	-1.407	-1.357
|Bias| < Bias CL?	Yes	Yes	Yes	Yes
number of terms	*6*	*5*	*6*	*5*

Table 4b. Calibration and validation statistics (Step-up regression)

Energy required to shear

	Step-up Regression 2,2,2						Step-up Regression 2,5,5					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	29.33	13.83	6.65	5.29	5.89	3.23	25.70	21.99	5.71	1.60	4.92	1.70
R^2	0.470	0.625	0.684	0.725	0.766	0.784	0.436	0.663	0.709	0.715	0.778	0.792
SEC	1.873	1.575	1.445	1.349	1.244	1.196	1.932	1.492	1.387	1.373	1.211	1.173
SEC CL	2.420	2.035	1.867	1.743	1.608	1.546	2.497	1.928	1.792	1.774	1.565	1.516
SEV(C)	1.973	1.672	1.561	1.476	1.390	1.318	2.022	1.571	1.476	1.470	1.357	1.319
r^2	0.371	0.344	0.310	0.205	0.202	0.168	0.375	0.531	0.557	0.557	0.631	0.635
Bias	1.120	0.950	0.870	0.810	0.775	0.720	1.160	0.900	0.830	0.820	0.730	0.700
Bias CL	2.407	2.024	1.857	1.734	1.599	1.537	2.483	1.917	1.783	1.765	1.556	1.507
SEP (C)	2.430	2.050	1.880	1.750	1.620	1.550	2.510	1.940	1.800	1.780	1.570	1.520
Slope	1.000	0.795	0.784	0.598	0.549	0.498	0.643	0.606	0.616	0.633	0.644	0.633
Intercept	-0.120	3.030	3.290	6.090	6.950	7.790	5.390	5.790	5.560	5.270	5.050	5.170
R.S.D.	1.896	1.803	1.773	1.769	1.732	2.058	1.891	1.806	1.698	1.658	2.317	1.945
|Bias| - Bias CL	-1.287	-1.074	-0.987	-0.924	-0.824	-0.817	-1.323	-1.017	-0.953	-0.945	-0.826	-0.807
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Energy required to comminute

	Step-up Regression 2,2,2						Step-up Regression 2,5,5					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	81.33	12.82	9.62	6.10	6.71	2.92	67.30	8.96	2.73	4.91	5.06	4.26
R^2	0.715	0.794	0.840	0.864	0.887	0.894	0.974	0.741	0.755	0.782	0.810	0.830
SEC	20.719	17.629	15.538	14.330	13.061	12.620	22.149	19.757	19.213	18.105	16.921	15.983
SEC CL	2.420	2.035	1.867	1.743	1.608	1.546	2.497	1.928	1.792	1.774	1.565	1.516
SEV(C)	21.511	18.353	16.378	15.230	13.967	13.633	22.769	20.547	20.096	19.092	18.262	17.484
r^2	0.322	0.424	0.421	0.411	0.371	0.373	0.183	0.199	0.148	0.099	0.114	0.098
Bias	12.430	10.580	9.320	8.600	7.840	7.570	13.290	11.850	11.530	10.860	10.150	9.590
Bias CL	26.627	22.656	19.969	18.416	16.785	16.219	28.465	25.391	24.692	23.268	21.746	20.541
SEP (C)	26.940	22.920	20.200	18.630	16.980	16.410	28.790	25.680	24.980	23.540	22.000	20.780
Slope	0.605	0.623	0.577	0.560	0.524	0.521	0.491	0.518	0.441	0.346	0.365	0.317
Intercept	47.100	43.900	48.900	52.900	58.300	57.800	60.100	58.500	70.800	84.600	82.700	89.600
R.S.D.	29.810	27.480	27.550	27.790	28.720	28.670	32.720	32.400	33.420	34.370	34.070	34.380
|Bias| - Bias CL	-14.197	-12.076	-10.649	-9.816	-8.945	-8.649	-15.175	-13.541	-13.162	-12.408	-11.596	-10.951
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4b. (cont'd)

Energy required to compress	Step-up Regression 2,2,2						Step-up Regression 2,5,5					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	7.28	6.24	3.22	2.65	3.10	0.00	8.07	4.23	4.08	2.21	5.36	1.87
R^2	0.164	0.285	0.334	0.370	0.440	0.530	0.181	0.258	0.327	0.445	0.520	0.535
SEC	0.270	0.250	0.241	0.235	0.221	0.203	0.268	0.255	0.243	0.220	0.205	0.202
SEC CL	2.420	2.035	1.867	1.743	1.608	1.546	2.497	1.928	1.792	1.774	1.565	1.516
SEV(C)	0.277	0.259	0.252	0.248	0.238	0.226	0.276	0.268	0.257	0.241	0.227	0.222
r^2	0.067	0.089	0.087	0.104	0.067	0.033	0.039	0.064	0.038	0.005	0.010	0.006
Bias	0.160	0.150	0.140	0.140	0.130	0.120	0.160	0.150	0.150	0.130	0.120	0.120
Bias CL	0.347	0.321	0.310	0.302	0.284	0.261	0.344	0.328	0.312	0.283	0.263	0.260
SEP (C)	0.350	0.330	0.310	0.310	0.290	0.260	0.350	0.330	0.320	0.290	0.270	0.260
Slope	0.367	0.394	0.345	0.341	0.280	0.156	0.267	0.295	0.198	0.068	0.085	0.063
Intercept	2.380	2.270	2.460	2.470	2.690	3.160	2.750	2.640	3.010	3.490	3.420	3.510
R.S.D.	0.235	0.232	0.235	0.239	0.239	0.239	0.236	0.233	0.230	0.229	0.233	0.239
|Bias| - Bias CL	-0.187	-0.171	-0.170	-0.162	-0.154	-0.141	-0.184	-0.178	-0.162	-0.153	-0.143	-0.140
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Digestibility of dry matter *in vivo*	Step-up Regression 2,2,2						Step-up Regression 2,5,5					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	72.42	5.79	8.71	16.80	13.18	2.86	80.75	12.35	8.41	7.34	6.03	3.72
R^2	0.616	0.714	0.830	0.862	0.883	0.906	0.679	0.826	0.897	0.909	0.919	0.924
SEC	3.555	3.069	2.365	2.127	1.962	1.755	3.248	2.394	1.840	1.728	1.635	1.586
SEC CL	2.420	2.035	1.867	1.743	1.608	1.546	2.497	1.928	1.792	1.774	1.565	1.516
SEV(C)	3.666	3.250	2.557	2.312	2.152	1.956	3.328	2.457	1.972	1.884	1.828	1.782
r^2	0.785	0.712	0.664	0.787	0.884	0.768	0.755	0.740	0.884	0.893	0.876	0.869
Bias	2.130	1.840	1.420	1.280	1.180	1.050	1.950	1.440	1.100	1.040	0.980	0.950
Bias CL	0.347	0.321	0.310	0.302	0.284	0.261	0.344	0.328	0.312	0.283	0.263	0.260
SEP (C)	4.620	3.990	3.070	2.770	2.550	2.280	4.220	3.110	2.390	2.250	2.130	2.060
Slope	1.050	0.805	0.792	0.826	0.777	0.731	1.090	1.050	0.889	0.880	0.866	0.885
Intercept	-2.180	10.300	11.000	9.040	11.900	14.900	-5.290	-3.300	5.850	6.430	7.210	6.080
R.S.D.	2.484	2.877	2.584	2.652	2.734	3.108	2.476	1.825	1.825	1.750	1.884	1.940
|Bias| - Bias CL	1.783	1.519	1.110	0.978	0.896	0.789	1.606	1.112	0.788	0.757	0.717	0.690
|Bias| < Bias CL?	No	No	No	No	No	No	No	No	No	No	No	No

Table 4b. (cont'd)

Digestibility of dry matter *in vitro*

	Step-up Regression 2,2,2						Step-up Regression 2,5,5					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	73.30	5.73	8.71	17.00	13.23	2.99	81.21	12.38	8.48	7.23	6.07	3.72
R^2	0.692	0.733	0.788	0.863	0.905	0.915	0.715	0.791	0.833	0.863	0.884	0.894
SEC	3.913	3.645	2.251	2.610	2.177	2.058	3.768	3.222	2.883	2.616	2.407	2.294
SEC CL	2.420	2.035	1.867	1.743	1.608	1.546	2.497	1.928	1.792	1.774	1.565	1.516
SEV(C)	4.020	3.186	3.411	2.781	2.324	2.203	3.855	3.360	3.063	2.809	2.615	2.490
r^2	0.731	0.694	0.687	0.644	0.685	0.671	0.735	0.856	0.845	0.849	0.801	0.800
Bias	2.350	2.190	1.950	1.570	1.310	1.230	2.260	1.930	1.730	1.570	1.440	1.380
Bias CL	5.029	4.684	2.893	3.354	2.798	2.645	4.842	4.141	3.705	3.362	3.093	2.948
SEP (C)	5.090	4.740	4.230	3.390	2.830	2.680	4.900	4.190	3.750	3.400	3.130	2.980
Slope	0.946	0.868	0.861	0.877	0.860	0.830	1.080	0.994	1.020	0.976	0.975	0.914
Intercept	2.000	5.890	6.550	6.140	7.240	9.150	-4.700	-0.410	-1.970	0.240	0.240	4.040
R.S.D.	3.565	3.601	3.842	3.882	4.143	3.895	3.576	2.637	2.733	2.694	3.097	3.103
|Bias| - Bias CL	-2.679	-2.494	-0.943	-1.784	-1.488	-1.415	-2.582	-2.211	-1.975	-1.792	-1.653	-1.568
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Energy required to shear

	Step-up Regression 2,10,5						Step-up Regression 2,10,10					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	25.11	14.92	5.87	4.42	7.61	1.89	23.54	15.23	4.01	4.30	4.35	4.66
R^2	0.430	0.606	0.661	0.697	0.755	0.763	0.413	0.598	0.641	0.678	0.721	0.755
SEC	1.942	1.613	1.496	1.415	1.273	1.252	1.970	1.631	1.541	1.460	1.358	1.274
SEC CL	2.510	2.084	1.933	1.829	1.645	1.618	2.546	2.108	1.991	1.887	1.755	1.646
SEV(C)	2.020	1.674	1.611	1.541	1.403	1.392	2.047	1.689	1.612	1.569	1.494	1.411
r^2	0.273	0.398	0.456	0.473	0.476	0.498	0.291	0.333	0.401	0.454	0.517	0.541
Bias	1.170	0.970	0.900	0.850	0.760	0.750	1.180	0.980	0.920	0.880	0.810	0.760
Bias CL	2.496	2.073	1.923	1.818	1.636	1.609	2.532	2.096	1.980	1.876	1.745	1.637
SEP (C)	2.520	2.100	1.950	1.840	1.650	1.630	2.560	2.120	2.000	1.900	1.760	1.660
Slope	0.706	0.723	0.717	0.707	0.610	0.616	0.737	0.581	0.639	0.653	0.715	0.709
Intercept	4.150	3.950	4.320	4.260	5.620	5.440	3.720	5.850	5.040	5.040	4.130	4.160
R.S.D.	2.170	2.193	2.343	2.367	2.524	2.375	2.179	1.607	1.666	1.644	1.889	1.893
|Bias| - Bias CL	-1.326	-1.103	-1.023	-0.968	-0.876	-0.859	-1.352	-1.116	-1.060	-0.996	-0.935	-0.877
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4b. (cont'd)

Energy required to comminute	Step-up Regression 2,10,5						Step-up Regression 2,10,10					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	76.72	5.31	2.76	2.18	1.68	1.01	74.85	5.39	2.13	2.96	4.38	1.49
R^2	0.703	0.739	0.754	0.763	0.772	0.800	0.698	0.735	0.745	0.761	0.787	0.791
SEC	21.158	19.825	19.267	18.887	18.518	17.344	21.345	19.977	19.611	18.982	17.929	17.768
SEC CL	2.510	2.084	1.933	1.829	1.645	1.618	2.546	2.108	1.991	1.887	1.755	1.646
SEV(C)	21.803	20.707	20.279	19.690	19.499	18.691	22.033	20.904	20.985	19.911	18.777	18.634
r^2	0.460	0.468	0.414	0.394	0.330	0.215	0.434	0.450	0.408	0.397	0.357	0.387
Bias	12.690	11.890	11.560	11.330	11.110	10.410	12.810	11.990	11.700	11.390	10.760	10.660
Bias CL	27.191	25.478	24.761	24.273	23.799	22.290	27.432	25.674	25.203	24.395	23.042	22.835
SEP (C)	27.510	25.770	25.050	24.550	24.070	22.550	27.750	25.970	25.490	24.680	23.310	23.100
Slope	0.793	0.737	0.688	0.649	0.598	0.468	0.776	0.729	0.694	0.645	0.622	0.633
Intercept	18.300	24.500	31.800	39.600	48.100	67.100	20.200	25.600	30.800	39.000	43.600	42.200
R.S.D.	26.610	26.420	27.720	28.170	29.640	32.080	27.230	26.850	27.860	28.100	29.030	28.350
|Bias| - Bias CL	-14.501	-13.588	-13.201	-12.943	-12.689	-11.880	-14.622	-13.684	-13.503	-13.005	-12.282	-12.175
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Energy required to compress	Step-up Regression 2,10,5						Step-up Regression 2,10,10					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	8.16	2.24	8.06	4.06	1.97	4.98	6.50	4.94	4.91	1.75	3.54	3.83
R^2	0.183	0.214	0.364	0.457	0.532	0.592	0.147	0.243	0.397	0.412	0.461	0.512
SEC	0.267	0.262	0.236	0.218	0.202	0.189	0.273	0.257	0.230	0.227	0.217	0.207
SEC CL	2.510	2.084	1.933	1.829	1.645	1.618	2.546	2.108	1.991	1.887	1.755	1.646
SEV(C)	0.278	0.275	0.252	0.235	0.218	0.210	0.283	0.273	0.250	0.250	0.247	0.235
r^2	0.010	0.028	0.052	0.076	0.086	0.053	0.006	0.057	0.045	0.052	0.035	0.029
Bias	0.160	0.160	0.140	0.130	0.120	0.110	0.160	0.150	0.140	0.140	0.130	0.120
Bias CL	0.343	0.337	0.303	0.280	0.260	0.243	0.351	0.330	0.296	0.292	0.279	0.266
SEP (C)	0.350	0.340	0.310	0.280	0.260	0.250	0.360	0.330	0.300	0.290	0.280	0.270
Slope	0.127	0.212	0.239	0.252	0.218	0.142	0.102	0.294	0.216	0.212	0.149	0.149
Intercept	3.270	2.960	2.850	2.800	2.930	3.210	3.360	2.640	2.940	2.950	3.180	3.190
R.S.D.	0.234	0.233	0.235	0.236	1.942	1.495	1.736	1.938	1.980	2.030	2.179	2.183
|Bias| - Bias CL	-0.183	-0.177	-0.163	-0.150	-0.140	-0.133	-0.191	-0.180	-0.156	-0.152	-0.149	-0.146
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4b. (cont'd)

Digestibility of dry matter *in vivo*	Step-up Regression 2,10,5						Step-up Regression 2,10,10					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	91.59	9.46	9.77	7.10	2.58	4.12	93.60	6.52	16.07	4.36	4.68	4.94
R^2	0.700	0.867	0.902	0.916	0.927	0.935	0.675	0.815	0.898	0.912	0.922	0.927
SEC	3.139	2.095	1.794	1.660	1.545	1.457	3.271	2.467	1.828	1.698	1.598	1.546
SEC CL	2.510	2.084	1.933	1.829	1.645	1.618	2.546	2.108	1.991	1.887	1.755	1.646
SEV(C)	3.332	2.282	1.997	1.830	1.694	1.607	3.357	2.572	2.016	1.905	1.840	1.787
r^2	0.777	0.856	0.888	0.871	0.887	0.881	0.828	0.831	0.809	0.836	0.877	0.892
Bias	1.880	1.260	1.080	1.000	0.930	0.870	1.960	1.480	1.100	1.020	0.960	0.930
Bias CL	0.343	0.337	0.303	0.280	0.260	0.243	0.351	0.330	0.296	0.292	0.279	0.266
SEP (C)	4.080	2.720	2.330	2.160	2.010	1.890	4.250	3.210	2.380	2.210	2.080	2.010
Slope	0.892	0.880	0.924	0.870	0.851	0.837	1.130	0.991	0.812	0.829	0.840	0.865
Intercept	7.380	6.750	3.930	6.850	8.320	8.960	-6.490	0.210	9.960	9.030	8.710	7.270
R.S.D.	2.531	2.034	1.791	1.927	1.799	1.846	2.222	2.201	2.344	2.172	1.876	1.761
|Bias| - Bias CL	1.537	0.923	0.777	0.720	0.670	0.627	1.609	1.150	0.804	0.728	0.681	0.664
|Bias| < Bias CL?	No	No	No	No	No	No	No	No	No	No	No	No

Digestibility of dry matter *in vitro*	Step-up Regression 2,10,5						Step-up Regression 2,10,10					
	1 term	2 terms	3 terms	4 terms	5 terms	6 terms	1 term	2 terms	3 terms	4 terms	5 terms	6 terms
Lowest partial F-ratio	94.12	6.62	16.01	4.48	4.61	5.01	92.14	9.60	9.70	10.55	2.67	4.41
R^2	0.744	0.784	0.856	0.871	0.886	0.901	0.740	0.797	0.842	0.881	0.888	0.900
SEC	3.568	•3.283	2.680	2.532	2.384	2.224	3.596	3.182	2.802	2.430	2.361	2.235
SEC CL	2.510	2.084	1.933	1.829	1.645	1.618	2.546	2.108	1.991	1.887	1.755	1.646
SEV(C)	3.633	3.371	2.785	2.667	2.563	2.364	3.655	3.280	2.892	2.618	2.525	2.416
r^2	0.828	0.816	0.813	0.802	0.819	0.851	0.823	0.807	0.810	0.844	0.818	0.823
Bias	2.140	1.970	1.610	1.520	1.430	1.330	2.160	1.910	1.680	1.460	1.420	1.340
Bias CL	4.585	4.219	3.444	3.254	3.064	2.858	4.621	4.089	3.601	3.123	3.034	2.872
SEP (C)	4.640	4.270	3.480	3.290	3.100	2.890	4.680	4.140	3.640	3.160	3.070	2.910
Slope	0.960	0.971	0.906	0.862	0.867	0.864	0.937	0.927	0.882	0.935	0.881	0.841
Intercept	2.120	1.280	4.530	7.230	7.380	7.610	3.490	3.660	5.790	3.260	6.140	8.660
R.S.D.	2.978	3.002	3.088	2.952	2.681	2.922	3.023	2.742	2.959	2.846	0.231	0.239
|Bias| - Bias CL	-2.445	-2.249	-1.834	-1.734	-1.634	-1.528	-2.461	-2.179	-1.921	-1.663	-1.614	-1.532
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 4c. Calibration and validation statistics (multivariate regressions)

	PCR		PLS		MPLS	
Energy required to shear						
	2.5.5	2.10.10	2.5.5	2.10.10	2.5.5	2.10.10
R^2	0.847	0.752	0.639	0.601	0.601	0.582
SEC	1.036	1.290	1.545	1.624	1.550	1.586
SEC CL	1.199	1.493	1.788	1.879	1.793	1.835
SECV	1.750	1.592	1.788	1.933	1.600	1.583
r^2	0.5441	0.4876	0.4938	0.4157	0.3080	0.3563
Bias	0.620	0.770	0.930	0.970	0.930	0.950
Bias CL	1.331	1.658	1.986	2.087	1.992	2.038
SEP (C)	1.350	1.680	2.010	2.110	2.020	2.060
Slope	0.6540	0.6850	0.7390	0.6270	0.5220	0.6000
Intercept	5.2900	4.8100	3.7500	5.4500	7.3100	6.0200
R.S.D.	1.671	1.776	1.761	1.892	2.065	1.992
|Bias| - Bias CL	-0.711	-0.888	-1.056	-1.117	-1.062	-1.088
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes
Energy required to comminute						
	PCR		PLS		MPLS	
	2.5.5	2.10.10	2.5.5	2.10.10	2.5.5	2.10.10
R^2	0.584	0.574	0.605	0.595	0.556	0.558
SEC	23.378	23.682	22.788	23.075	24.164	24.101
SEC CL	27.048	27.400	26.366	26.698	27.958	27.885
SECV	26.030	26.121	25.548	25.683	26.409	26.252
r^2	0.349	0.337	0.332	0.325	0.33	0.328
Bias	14.030	14.210	13.670	13.840	14.500	14.460
Bias CL	30.044	30.435	29.286	29.655	31.055	30.974
SEP (C)	30.390	30.790	29.620	30.000	31.410	31.330
Slope	0.649	0.636	0.644	0.632	0.657	0.638
Intercept	37.3	39.2	38.1	39.7	36.6	39.1
R.S.D.	28.246	28.676	28.714	28.884	28.651	28.900
|Bias| - Bias CL	-16.014	-16.225	-15.616	-15.815	-16.555	-16.514
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes
Energy required to compress						
	PCR		PLS		MPLS	
	2.5.5	2.10.10	2.5.5	2.10.10	2.5.5	2.10.10
R^2	0.251	0.160	0.231	0.208	0.038	0.040
SEC	0.225	0.241	0.265	0.269	0.260	0.260
SEC CL	0.260	0.279	0.307	0.311	0.301	0.301
SECV	0.299	0.277	0.301	0.307	0.301	0.299
r^2	0.0220	0.0120	0.0130	0.0090	0.0060	0.0080
Bias	0.140	0.140	0.160	0.160	0.160	0.160
Bias CL	0.289	0.310	0.341	0.346	0.334	0.334
SEP (C)	0.290	0.310	0.340	0.350	0.340	0.340
Slope	0.2290	0.2270	0.1530	0.1330	0.2290	0.2590
Intercept	2.8900	2.9000	3.1700	3.2500	2.8900	2.7700
R.S.D.	0.235	0.236	0.236	0.237	0.237	0.237
|Bias| - Bias CL	-0.149	-0.170	-0.181	-0.186	-0.174	-0.174
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes

Table 4c (cont'd) Calibration and validation statistics (multivariate regressions)

Digestibility of dry matter *in vivo*

	PCR		PLS		MPLS	
	2,5,5	2,10,10	2,5,5	2,10,10	2,5,5	2,10,10
R^2	0.909	0.900	0.958	0.937	0.571	0.892
SEC	1.638	1.711	1.109	1.356	3.756	1.911
SEC CL	1.895	1.980	1.283	1.569	4.346	2.211
SECV	2.159	2.075	1.957	1.776	3.797	2.180
r^2	0.9022	0.8865	0.8447	0.8457	0.6963	0.8671
Bias	0.980	1.030	0.670	0.810	2.250	1.150
Bias CL	2.105	2.199	1.425	1.743	4.827	2.456
SEP (C)	2.130	2.220	1.440	1.760	4.880	2.480
Slope	0.848	0.807	0.839	0.822	0.981	0.745
Intercept	8.77	11.1	8.65	9.41	1.99	14.6
R.S.D.	1.704	1.834	2.143	2.139	2.914	1.984
|Bias| - Bias CL	-1.125	-1.169	-0.755	-0.933	-2.577	-1.306
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes

Digestibility of dry matter *in vitro*

	PCR		PLS		MPLS	
	2,5,5	2,10,10	2,5,5	2,10,10	2,5,5	2,10,10
R^2	0.820	0.790	0.780	0.760	0.420	0.490
SEC	2.880	3.100	3.330	3.470	5.380	4.850
SEC CL	3.332	3.587	3.853	4.015	6.225	5.611
SECV	3.170	3.560	3.830	3.900	5.690	4.780
r^2	0.8120	0.7730	0.8530	0.8040	0.6910	0.6690
Bias	1.730	1.860	2.000	2.080	3.230	2.910
Bias CL	3.701	3.984	4.280	4.459	6.914	6.233
SEP (C)	3.740	4.030	4.330	4.510	6.990	6.310
Slope	0.9180	0.9840	0.9530	0.6120	1.1200	0.8650
Intercept	3.4700	-0.3600	2.3100	4.6300	-7.5100	6.1800
R.S.D.	3.053	3.363	2.836	3.089	3.911	4.002
|Bias| - Bias CL	-1.971	-2.124	-2.280	-2.379	-3.684	-3.323
|Bias| < Bias CL?	Yes	Yes	Yes	Yes	Yes	Yes

Table 5. Standard error of laboratory determination (SEL)

	Energy required to shear (kJ/m^2)	Energy required to comminute (kJ/kg DM)	Energy required to compress (kJ/kg DM)	Digestibility of dry matter *in vivo* (%)	Digestibility of dry matter *in vitro* (%)
Mean SEL (n=65)	0.796	5.830	0.078	not available	0.314
Median SEL	0.788	5.492	0.085	not available	0.270
Maximum SEL	2.044	13.098	0.211	not available	1.126
Minimum SEL	0.114	0.760	0.019	not available	0.005
SEL CL (using mean SEL)	1.035	7.319	0.101	not available	0.408
SEL CL (using median SEL)	1.024	7.140	0.111	not available	0.351

Table 6a. Components of possible prediction equations from stepwise and step-up regression analyses.

	Coefficient	Wavelength	Coefficient	Wavelength
	Energy required to shear			
Regression analysis Mathematical treatment	Stepwise 2,2,2 (6 terms)		Step-up 2,5,5 (2 terms)	
	19.95		28.09	
	2452.05	2048	1035.77	2048
	-4255.61	1988	700.12	1858
	3823.49	1458		
	-5319.88	1718		
	5149.38	1828		
	10238.46	1168		
	Energy required to compress			
Regression analysis Mathematical treatment	Stepwise 2,10,10 (4 terms)		Step-up 2,10,5 (3 terms)	
	-0.71		2.49	
	-29.02	2278	-31.05	1728
	112.57	1588	-108.89	1548
	-78.48	1728	-405.95	1268
	-911.04	1238		
	Energy required to comminute			
Regression analysis Mathematical treatment	Stepwise 2,10,5 (4 terms)		Step-up 2,10,5 (1 term)	
	231.42		-69.08	
	-3003.37	2128	-1521.33	2268
	4290.19	2408		
	-4955.12	2018		
	18224.74	1138		
	Digestibility of dry matter *in vivo*			
Regression analysis Mathematical treatment	Stepwise 2,5,5 (6 terms)		Step-up 2,10,5 (3 terms)	
	48.62		49.16	
	-337.08	1918	-812.43	1698
	-8799.69	1238	252.82	1418
	8162.72	1158	-943.77	1618
	1249.01	1688		
	519.48	1208		
	-161.84	2248		
	Digestibility of dry matter *in vitro*			
Regression analysis Mathematical treatment	Stepwise 2,5,5 (5 terms)		Step-up 2,10,10 (4 terms)	
	63.43		54.29	
	-958.01	1918	-1171.70	1698
	981.30	1208	311.12	1418
	-2188.89	1688	-2657.69	1818
	2003.05	2158	-2319.81	1228
	-1491.99	1748		

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Energy required to shear		Energy required to compress		Energy required to comminute			
PCR (2,6,6)		PCR (2,6,6)		PCR (2,6,6)		PLS (2,6,6)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
-3.33		3.35		-22.8		-16.44	
18.1	1108	0.17	1108	93.07	1108	91.01	1108
1.78	1118	0.02	1118	6.5	1118	7.19	1118
-0.2	1128	-0.01	1128	-7.27	1128	-5.63	1128
-0.84	1138	-0.01	1138	-0.79	1138	-0.13	1138
1.15	1148	0.01	1148	3.98	1148	5.58	1148
-0.85	1158	-0.01	1158	-10.39	1158	-8.55	1158
0.13	1168	0	1168	-4.8	1168	-4.72	1168
0.64	1178	0.03	1178	13.75	1178	13.27	1178
-0.04	1188	0.04	1188	19.07	1188	17.38	1188
-0.84	1198	0	1198	5.06	1198	0.44	1198
-1.14	1208	-0.03	1208	-8.92	1208	-13.98	1208
-1.71	1218	-0.05	1218	-20.83	1218	-23.8	1218
-1.73	1228	-0.04	1228	-17.9	1228	-15.15	1228
-0.85	1238	-0.01	1238	-3.26	1238	-0.82	1238
0.12	1248	0	1248	-0.65	1248	1.6	1248
0.5	1258	0	1258	-2.55	1258	-0.82	1258
-0.9	1268	-0.01	1268	-4.67	1268	-3.84	1268
-1.25	1278	0	1278	1.29	1278	1.1	1278
-0.25	1288	0.01	1288	5.24	1288	4.93	1288
0.2	1298	0.02	1298	5.9	1298	7.12	1298
-0.1	1308	0.03	1308	9.22	1308	10.4	1308
-0.66	1318	0.04	1318	14.26	1318	16.14	1318
1.25	1328	0.06	1328	22.7	1328	23.58	1328
5	1338	0.07	1338	27.63	1338	27.65	1338
2.34	1348	0.03	1348	6.64	1348	10.27	1348
-2.37	1358	-0.06	1358	-26.23	1358	-24.35	1358
-10.62	1368	-0.15	1368	-66.38	1368	-60.7	1368
-9.89	1378	-0.01	1378	-1.83	1378	2.2	1378
-1.68	1388	0.16	1388	67.77	1388	67.91	1388
8.65	1398	0.3	1398	125.67	1398	115.99	1398
23.88	1408	0.49	1408	188.24	1408	174.79	1408
13.87	1418	0.2	1418	67.19	1418	62.69	1418
-12.53	1428	-0.37	1428	-153.54	1428	-139.99	1428

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Energy required to shear		Energy required to compress		Energy required to comminute			
PCR (2,6,8)		PCR (2,6,8)		PCR (2,6,8)		PLS (2,6,8)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
-10.01	1438	-0.39	1438	-145.28	1438	-137.82	1438
-1.04	1448	-0.21	1448	-68.74	1448	-75.27	1448
2.09	1458	-0.13	1458	-37.31	1458	-47.38	1458
-2.69	1468	-0.11	1468	-49.09	1468	-48.54	1468
-8.05	1478	-0.14	1478	-70.4	1478	-59.94	1478
-1.2	1488	-0.08	1488	-26.64	1488	-28.08	1488
-2.08	1498	-0.01	1498	-1.87	1498	-3.2	1498
-1.69	1508	0.01	1508	4.61	1508	3.33	1508
0.35	1518	0.07	1518	28.89	1518	28.91	1518
2.8	1528	0.12	1528	49.84	1528	48.03	1528
-0.01	1538	0.08	1538	34.38	1538	33.02	1538
-1.83	1548	0	1548	-3.32	1548	0.49	1548
-3.7	1558	-0.04	1558	-21.79	1558	-17.82	1558
-0.66	1568	-0.01	1568	-4.61	1568	-3.35	1568
-1.99	1578	-0.04	1578	-13.08	1578	-15.39	1578
-3.67	1588	-0.09	1588	-43.91	1588	-40.21	1588
-5.26	1598	-0.07	1598	-30.2	1598	-32.77	1598
0.08	1608	-0.01	1608	-7.28	1608	-5.93	1608
2.89	1618	0.04	1618	17.4	1618	15	1618
0.22	1628	0.09	1628	34.68	1628	33.13	1628
-0.98	1638	0.13	1638	49.47	1638	48.83	1638
18.23	1648	0.1	1648	53.35	1648	44.32	1648
10.67	1658	0	1658	-3.16	1658	-2.24	1658
6.52	1668	-0.22	1668	-82.09	1668	-80.94	1668
-20.53	1678	-0.07	1678	-60.38	1678	-36.22	1678
-6.15	1688	0.15	1688	55.65	1688	60.49	1688
7.4	1698	0.08	1698	48.43	1698	42.6	1698
4.76	1708	0.08	1708	34.19	1708	27.79	1708
-19.73	1718	-0.09	1718	-54.88	1718	-46.38	1718
-5.98	1728	-0.13	1728	-54.69	1728	-69.44	1728
19.24	1738	0.15	1738	78.27	1738	63.67	1738
6.42	1748	0.19	1748	90.94	1748	91.13	1748
-3.1	1758	0.08	1758	21.41	1758	20.27	1758
-4.03	1768	-0.1	1768	-47.2	1768	-48.58	1768
-1.47	1778	-0.11	1778	-42.48	1778	-39.05	1778
-0.44	1788	-0.09	1788	-38.22	1788	-33.03	1788
1.72	1798	-0.01	1798	-2.33	1798	-3.76	1798

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Energy required to shear		Energy required to compress		Energy required to comminute			
PCR (2,6,6)		PCR (2,6,6)		PCR (2,6,6)		PLS (2,6,6)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
2.76	1808	0.05	1808	20.97	1808	18.41	1808
-3.79	1818	-0.01	1818	-6.56	1818	-5.17	1818
-4.32	1828	-0.07	1828	-30.81	1828	-26.5	1828
-2.97	1838	-0.05	1838	-17.29	1838	-17.64	1838
1.97	1848	0.03	1848	17.65	1848	15.59	1848
-2.48	1858	0.06	1858	28.06	1858	28.11	1858
-6.48	1868	0.08	1868	42.2	1868	40.46	1868
-10.22	1878	0.23	1878	115.52	1878	106.98	1878
-1.64	1888	0.44	1888	219.15	1888	206.1	1888
31.11	1898	0.2	1898	98.82	1898	99.42	1898
2.3	1908	-0.35	1908	-179.9	1908	-157.11	1908
-25.69	1918	-0.47	1918	-251.3	1918	-220.58	1918
-12.22	1928	-0.34	1928	-171.93	1928	-172.09	1928
15.11	1938	-0.14	1938	-55.38	1938	-77.27	1938
26.89	1948	-0.03	1948	-6.17	1948	-23.21	1948
27.72	1958	-0.04	1958	-16.65	1958	-19.03	1958
6.93	1968	0.05	1968	12.02	1968	22.46	1968
-15.33	1978	0.23	1978	66.03	1978	86.86	1978
-9.25	1988	0.29	1988	85.84	1988	103.6	1988
-3.33	1998	0.27	1998	78.88	1998	96.03	1998
1.28	2008	0.32	2008	97.53	2008	115.14	2008
20.22	2018	0.25	2018	104.79	2018	99.25	2018
18.34	2028	0.08	2028	42.06	2028	33.39	2028
9.56	2038	-0.01	2038	23.98	2038	11.1	2038
5.59	2048	0.13	2048	101.85	2048	77.38	2048
-6.54	2058	0.21	2058	126.79	2058	109.6	2058
-16.75	2068	-0.2	2068	-75.99	2068	-71.48	2068
-18.33	2078	-0.48	2078	-206.62	2078	-186.9	2078
-10.13	2088	-0.36	2088	-151.16	2088	-143.65	2088
-5.78	2098	-0.26	2098	-107.24	2098	-104.69	2098
-8.44	2108	-0.26	2108	-108.06	2108	-107.49	2108
-6.28	2118	-0.23	2118	-91.06	2118	-91.23	2118
-4.49	2128	-0.23	2128	-97.55	2128	-93.37	2128
-16.58	2138	-0.2	2138	-101.35	2138	-85.08	2138
-9.08	2148	-0.01	2148	-13.78	2148	-9.31	2148
-2.68	2158	0.08	2158	37.5	2158	36.99	2158
3.19	2168	0.26	2168	118.43	2168	110.03	2168

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Energy required to shear		Energy required to compress		Energy required to comminute			
PCR (2,6,6)		PCR (2,6,6)		PCR (2,6,6)		PLS (2,6,6)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
4.27	2178	0.28	2178	122.68	2178	109.87	2178
-6.3	2188	0.16	2188	54.73	2188	58.98	2188
-13.33	2198	0.15	2198	38.08	2198	53.78	2198
-2.74	2208	0.35	2208	129.58	2208	147.19	2208
35.77	2218	0.36	2218	171.77	2218	149.55	2218
30.36	2228	0.42	2228	182.8	2228	168.64	2228
22.91	2238	0.22	2238	73.19	2238	86.39	2238
98.61	2248	-0.67	2248	-152.9	2248	-250.89	2248
-15.77	2258	-0.47	2258	-184.5	2258	-189.12	2258
-85.22	2268	-0.2	2268	-167.23	2268	-101.11	2268
-35.1	2278	-0.45	2278	-214.87	2278	-180.14	2278
27.27	2288	0.22	2288	148	2288	122.32	2288
4.27	2298	0.64	2298	352.88	2298	341.16	2298
-13.08	2308	0.29	2308	78.88	2308	63.68	2308
0.87	2318	-0.48	2318	-208.27	2318	-207.81	2318
-13.34	2328	-0.47	2328	-167.95	2328	-150.99	2328
-23.3	2338	-0.2	2338	-79.26	2338	-68.98	2338
0.66	2348	0.15	2348	62.44	2348	40.83	2348
7.98	2358	-0.07	2358	-23.09	2358	-30.25	2358
-15.62	2368	0.08	2368	25.53	2368	41.9	2368
-16.39	2378	0.05	2378	-3.86	2378	12.67	2378
-4.44	2388	-0.05	2388	-33.15	2388	-26.65	2388
21.16	2398	0.2	2398	98.53	2398	79.92	2398
49.9	2408	0.22	2408	130.67	2408	89.16	2408
22.34	2418	0.29	2418	120.05	2418	107.71	2418
-1.47	2428	0.22	2428	72.57	2428	84.86	2428
17.19	2438	0.03	2438	6.72	2438	3.78	2438
15.21	2448	0.11	2448	55.93	2448	45.74	2448
-14.12	2458	0.16	2458	59.69	2458	71.29	2458
-24.15	2468	-0.04	2468	-31.79	2468	-13.92	2468

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Digestibility of dry matter *in vitro*		Digestibility of dry matter *in vivo*			
PLS (2,5,5)		PCR (2,5,5)		PLS (2,5,5)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
59.77		40.56		63.64	
-96.28	1108	-181.5	1108	-78.7	1108
7.55	1118	12.91	1118	4	1118
12.25	1128	22.04	1128	8.88	1128
6.85	1138	19.51	1138	3.94	1138
6.74	1148	8.19	1148	7.08	1148
11.89	1158	5.29	1158	6.24	1158
4.45	1168	-0.92	1168	0.43	1168
-10.08	1178	-11.1	1178	-5.6	1178
-29.8	1188	-37.4	1188	-15.1	1188
-20.43	1198	-26.13	1198	-10.61	1198
-20.05	1208	-38.03	1208	-15.98	1208
-15.65	1218	-35.64	1218	-13.16	1218
2.41	1228	-13.39	1228	2.93	1228
6.62	1238	0.89	1238	6.37	1238
8.6	1248	14.13	1248	7.08	1248
7.47	1258	17.48	1258	5.99	1258
-1.32	1268	-7.44	1268	-0.25	1268
-7.39	1278	-22.67	1278	-4.08	1278
-0.79	1288	-1.06	1288	0.15	1288
3.48	1298	9.23	1298	3.72	1298
5.1	1308	13.17	1308	4.38	1308
6.23	1318	15.6	1318	6.03	1318
8.48	1328	25.91	1328	9.03	1328
17.78	1338	40.71	1338	13	1338
24.61	1348	51.12	1348	13.51	1348
-0.07	1358	4.6	1358	0.26	1358
-23.89	1368	-88.33	1368	-13.81	1368
-29.86	1378	-68.78	1378	-8.13	1378
-16.97	1388	5.08	1388	-1.4	1388
23.92	1398	32.14	1398	16.06	1398
60.7	1408	76.51	1408	32.06	1408
55.51	1418	90.64	1418	11.94	1418
-0.3	1428	-1.47	1428	-14.76	1428

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Digestibility of dry matter *in vitro*		Digestibility of dry matter *in vivo*			
PLS (2,6,6)		PCR (2,6,6)		PLS (2,6,6)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
-28.21	1438	-11.15	1438	-19.94	1438
-32.57	1448	10.5	1448	-19.24	1448
-28.08	1458	18.31	1458	-18.15	1458
1.48	1468	-3.82	1468	3.7	1468
18.21	1478	-18.48	1478	10.65	1478
-0.65	1488	-25.14	1488	-0.75	1488
-22.99	1498	-74.43	1498	-7.65	1498
-23.44	1508	-75.49	1508	-9.41	1508
-15.74	1518	-58.78	1518	-9.08	1518
-9.09	1528	-25.77	1528	-5.21	1528
-2.8	1538	-7.83	1538	-3.63	1538
10.62	1548	17.83	1548	4.56	1548
28.76	1558	52.98	1558	15.5	1558
6.02	1568	21.09	1568	2.31	1568
-8.8	1578	-27.42	1578	-3.09	1578
-18.09	1588	-42.59	1588	-5.77	1588
-9.28	1598	-63.69	1598	-8.48	1598
-8.88	1608	-3.08	1608	-0.65	1608
-3.82	1618	-1.62	1618	-0.87	1618
-3.58	1628	-2.81	1628	0.24	1628
0.65	1638	-9.18	1638	3.42	1638
0.5	1648	13.81	1648	0.86	1648
23.87	1658	61.39	1658	13.12	1658
64.92	1668	159.6	1668	28.91	1668
78.84	1678	101.05	1678	44.01	1678
-13.9	1688	-79.36	1688	-8.19	1688
-74.54	1698	-77.73	1698	-34	1698
-38.63	1708	-43.87	1708	-18.38	1708
24.48	1718	21.34	1718	2.17	1718
-17.91	1728	-25.8	1728	-31.77	1728
-43.01	1738	-40.51	1738	-21.21	1738
-29.25	1748	-28.11	1748	-5.24	1748
-18.33	1758	-4.55	1758	-11.67	1758
0.43	1768	2.68	1768	-0.49	1768
28.21	1778	20.91	1778	21.37	1778
18.92	1788	13.59	1788	13.25	1788
0.54	1798	9.35	1798	-0.93	1798

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Digestibility of dry matter *in vitro*		Digestibility of dry matter *in vivo*			
PLS (2,5,6)		PCR (2,5,6)		PLS (2,5,6)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
-2.44	1808	7.17	1808	-4.5	1808
-2.72	1818	-15.36	1818	-2.3	1818
-5.84	1828	-29.4	1828	-3.37	1828
-4.37	1838	-16.21	1838	-0.05	1838
-8.79	1848	2.3	1848	-2.23	1848
-7.72	1858	-0.87	1858	-3.79	1858
-29.93	1868	-21.29	1868	-9.61	1868
-98.16	1878	-82.33	1878	-34.56	1878
-116.18	1888	-102.15	1888	-52.89	1888
117.59	1898	211.27	1898	38.2	1898
165	1908	204.51	1908	66.78	1908
33.91	1918	-3.12	1918	28.1	1918
-35.31	1928	18.14	1928	-3.79	1928
-44.59	1938	35.39	1938	-19.45	1938
-9.26	1948	-8.24	1948	-6.41	1948
35.73	1958	-11.32	1958	15.95	1958
28.56	1968	-37.15	1968	13.49	1968
10.68	1978	-44.26	1978	2.03	1978
10.98	1988	-61.81	1988	0.57	1988
65.12	1998	-72.2	1998	31.07	1998
63.13	2008	-63.31	2008	38.57	2008
7.23	2018	37.37	2018	-1.21	2018
0.99	2028	183.21	2028	-9.38	2028
-10.85	2038	156.66	2038	-14.51	2038
-84.46	2048	-2.09	2048	-54.72	2048
-122.91	2058	-176.03	2058	-68.29	2058
-35.85	2068	-104.9	2068	-1.69	2068
34.94	2078	-7.7	2078	37.55	2078
28.83	2088	62.28	2088	27.17	2088
18.03	2098	54.28	2098	16.01	2098
5.09	2108	14.14	2108	15.52	2108
-9.58	2118	-40.31	2118	7.88	2118
9.79	2128	2.34	2128	13.25	2128
23.04	2138	26.94	2138	16.49	2138
-10.93	2148	-31.56	2148	-6.42	2148
-16.87	2158	3.05	2158	-9.12	2158
-41.78	2168	-66.48	2168	-27.35	2168

Table 6b. Components of possible prediction equations from multivariate regression analyses.

Digestibility of dry matter *in vitro*		Digestibility of dry matter *in vivo*			
PLS (2,6,6)		PCR (2,6,6)		PLS (2,6,6)	
Coefficient	Wavelength	Coefficient	Wavelength	Coefficient	Wavelength
-48.69	2178	-107.52	2178	-32.56	2178
-14.5	2188	-54.54	2188	-12.56	2188
-0.14	2198	-11.17	2198	4.5	2198
-7.15	2208	-2.14	2208	4.87	2208
-48.95	2218	-43.68	2218	-30.89	2218
-18.22	2228	-0.01	2228	-19.94	2228
88.33	2238	100.18	2238	14.89	2238
-24.11	2248	53.32	2248	-53.79	2248
55.99	2258	81.52	2258	16.98	2258
110.06	2268	48.93	2268	90.27	2268
52.16	2278	-9.18	2278	63.98	2278
-89.38	2288	25.1	2288	-35.59	2288
-109.99	2298	-47.83	2298	-77.98	2298
-54.11	2308	-23.3	2308	-61.38	2308
17.63	2318	-73.92	2318	22.34	2318
23.71	2328	-23.74	2328	48.6	2328
62.19	2338	13.64	2338	37.79	2338
-58.16	2348	-21.67	2348	-48.16	2348
-21.28	2358	-77.29	2358	-7.86	2358
4.01	2368	-88.75	2368	18.34	2368
32.53	2378	26.42	2378	17.8	2378
35.58	2388	66.01	2388	1.95	2388
-21.25	2398	22.17	2398	-27.54	2398
-70.01	2408	-26.98	2408	-50.39	2408
-16.86	2418	6.02	2418	-18.09	2418
61.66	2428	75.99	2428	17.75	2428
14.94	2438	58.83	2438	-3.66	2438
-11.88	2448	6.46	2448	-11.21	2448
5.35	2458	-4.33	2458	3.97	2458
10.49	2468	-33.25	2468	11.29	2468

Table 7. Descriptions of forages used in Table 8.

Sample in Table 8	Genus	Species	Variety	Common name	Part of plant	Process undergone	Stage of maturity	Regrowth
1	*Panicum*	*coloratum*	Kabulabula CPI 16796	Makarikari grass	aerial	dried and chaffed	mid bloom (9 weeks' regrowth)	mid bloom - regrowth
2	*Panicum*	*maximum*	Coloniao	Guinea grass	aerial	dried and chaffed	vegetative regrowth (4 weeks')	vegetative regrowth
3	*Panicum*	*coloratum*	Bambatsi	Makarikari grass	aerial	dried and chaffed	mid bloom (1 month's regrowth)	mid bloom - regrowth
4	*Panicum*	*maximum*	Hamil	Guinea grass	aerial	dried and chaffed	early bloom (1 month's regrowth)	early bloom - regrowth
5	*Panicum*	*coloratum var Makarikariense*	Burnett	Makarikari grass	aerial	dried and chaffed	mid bloom (6 weeks' regrowth)	mid bloom - regrowth
6	*Panicum*	*maximum var. trichoglume*	Petrie	Green Panic	aerial	dried and chaffed	mid bloom (4 weeks' regrowth)	mid bloom - regrowth

Table 8. Examples of energy required to shear, digestibility of dry matter *in vivo*, forage consumption constraint (FCC), and voluntary feed consumption (VFC)

Sample in Table 7	Energy required to shear, predicted using NIR[1] (kJ/m^2)	Digestibility of dry matter *in vivo*, predicted using NIR[2] (%)	Predicted FCC[3] (g OM/d/MBW)[4]	Predicted VFC[5] (g OM/d/MBW)	Actual VFC (g OM/d/MBW)	Actual VFC (g OM/d)
1	20.51	51.29	86.85	32.52	30.77	534
2	16.70	54.73	66.92	44.95	39.47	686
3	13.75	56.69	51.49	56.51	48.79	848
4	13.16	59.59	48.41	54.34	53.58	931
5	17.52	55.18	71.21	39.74	43.66	759
6	16.63	55.88	66.55	43.01	45.66	793

[1] Predicted using the calibration equation from stepwise regression analysis (Table 6a).
[2] Predicted using the calibration equation from stepwise regression analysis (Table 6a).
[3] Predicted using predicted energy required to shear, and the relationship between energy required to shear and FCC.
[4] Calculated from predicted FCC and predicted digestibility of dry matter *in vivo*.
[5] Abbreviations used: organic matter (OM), metabolic body weight (MBW) = $BW^{0.75}$

THE CLAIMS of the invention are as follows:

1. A method for determining a biomechanical property of a feed, the method comprising the steps of:

   (a) subjecting the feed to infrared radiation to obtain spectral data; and

   (b) using the spectral data to determine the biomechanical property;

   whereby, the biomechanical property of the feed is determined on the basis of the bond energies of the chemical constituents of the feed.

2. A method according to claim 1 wherein the biomechanical property of the feed is determined directly from the spectral data.

3. A method according to claim 1 wherein the spectral data is used to determine another property of the feed and the other property is used to determine the biomechanical property on the basis of a correlation between the other property and the biomechanical property.

4. A method according to claim 3 wherein the other property is ADF content, NDF content or lignin content.

5. A method according to claim 1 or claim 2 wherein the spectral data is a reflectance spectrum over a predetermined range of wavelengths.

6. A method according to claim 5 wherein the predetermined range is approximately 700nm to 3000nm.

7. A method according to claim 5 wherein the predetermined range is approximately 1100nm to 2500nm.

8. A method according to any one of claims 5 to 7 wherein the data obtained for the spectral range of approximately 1850nm to 1970nm is disregarded.

9. A method according to any one of claims 5 to 8 wherein the spectral data is recorded at 2nm intervals over the predetermined range.

10. A method according to claim 1 or claim 2 wherein the reflectance reading is taken at a combination of wavelengths.

11. A method according to claim 10 wherein the combination of wavelengths is selected from the group comprising: 1168nm, 1458nm, 1598nm, 1718nm, 1828nm, 2048nm, 1138nm, 2018nm, 2128nm, 2408nm, 1268nm, 1588nm, 1728nm, 2278nm, 1158nm, 1238nm, 1668nm, 1908nm, 2248nm, 1698nm, 1748nm, 1918nm and 2158nm.

12. A method according to claim 10 wherein the combination of wavelengths is 1168nm, 1458nm, 1598nm, 1718nm, 1828nm and 2048nm and the biomechanical property is shear energy.

13. A method according to claim 10 wherein the combination of wavelengths is 1268nm, 1588nm, 1728nm and 2278nm and the biomechanical property is compression energy.

14. A method according to claim 10 wherein the combination of wavelengths is 1138nm, 2018nm, 2128nm and 2408nm and the biomechanical property is comminution energy.

15. A method for determining a biomechanical property of a feed, the method comprising the steps of:

(a) subjecting the feed to infrared radiation to obtain spectral data; and

(b) comparing the spectral data obtained in (a) with a calibration equation to determine the biomechanical property;

whereby, the biomechanical property of the feed is determined on the basis of the bond energies of the chemical constituents of the feed.

16. A method according to claim 15 wherein the calibration equation is $y_1 = 19.95 + 10239.46\ R_{1168} + 3623.49\ R_{1458} - 4255.61\ R_{1598} - 5319.88\ R_{1718} + 5148.38\ R_{1828} + 2452.05\ R_{2048}$ and the biomechanical property is shear energy(y_1).

17. A method according to claim 15 wherein the calibration equation is $y_2 = 231.42 + 18224.74\ R_{1138} - 4955.12\ R_{2018} - 3005.37\ R_{2128} + 4290.18\ R_{2408}$ and the biomechanical property is comminution energy (y_2).

18. A method according to claim 15 wherein the calibration equation is $y_3 = -0.71 - 911.04\ R_{1268} + 112.57\ R_{1588} - 79.48\ R_{1728} - 28.02\ R_{2278}$ and the biomechanical property is compression energy (y_3).

19. A method according to any one of claims 15 to 18 wherein the calibration equation is determined from laboratory data establishing a correlation between reflectance and the biomechanical property.

20. A method according to any one of claims 1 to 19 wherein an additional property of the feed is also determined.

21. A method according to claim 20 wherein the additional property of the feed is digestibility of dry matter *in vivo* or *in vitro*.

22. A method for determining feed quality, the method comprising the steps of:

(a) subjecting the feed to infrared radiation to obtain spectral data;

(b) using the spectral data to determine a biomechanical property of the feed; and

(c) using the biomechanical property obtained in step (b) to determine feed quality;

whereby, the biomechanical property of the feed and thus feed quality is determined on the basis of the bond energies of the chemical constituents of the feed.

23. A method according to claim 22 wherein the feed quality is determined as a measure of voluntary feed consumption (VFC).

24. A method according to claim 22 wherein the feed quality is determined as a measure of forage consumption constraint (FCC).

25. A method substantially as herein described with reference to the description of the examples.

26. A spectrometer configured to carry out the method according to any one of claims 1 to 21 wherein the spectrometer is adapted to receive a sample of feed and determine a biomechanical property of the feed.

27. A spectrometer configured to carry out the method according to any one of claims 22 to 24 wherein the spectrometer is adapted to receive a sample of feed and determine the quality of the feed.

28. A spectrometer according to claim 26 or 27 further comprising a data processing means for determining the biomechanical property or the quality of the feed.

Figure 1

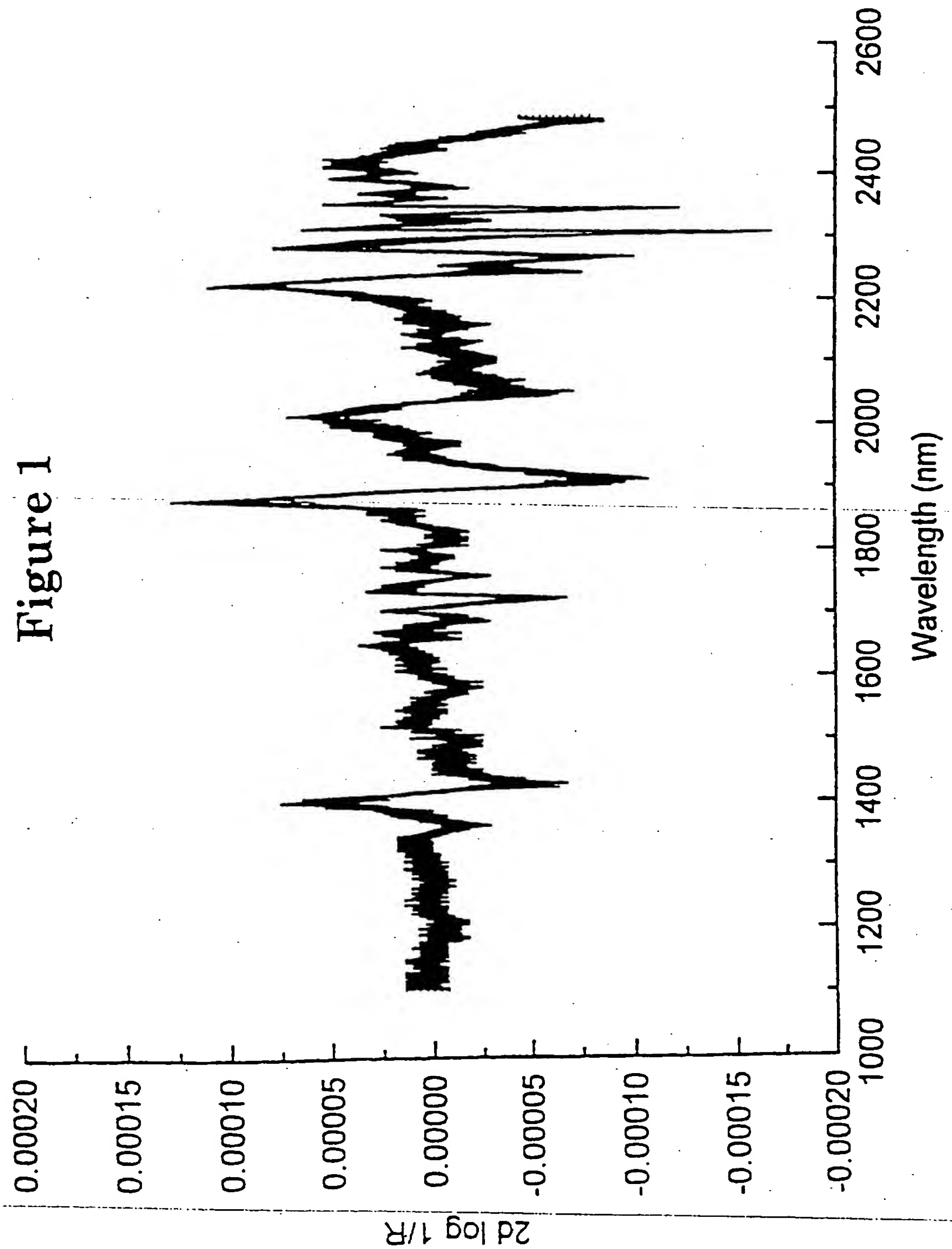
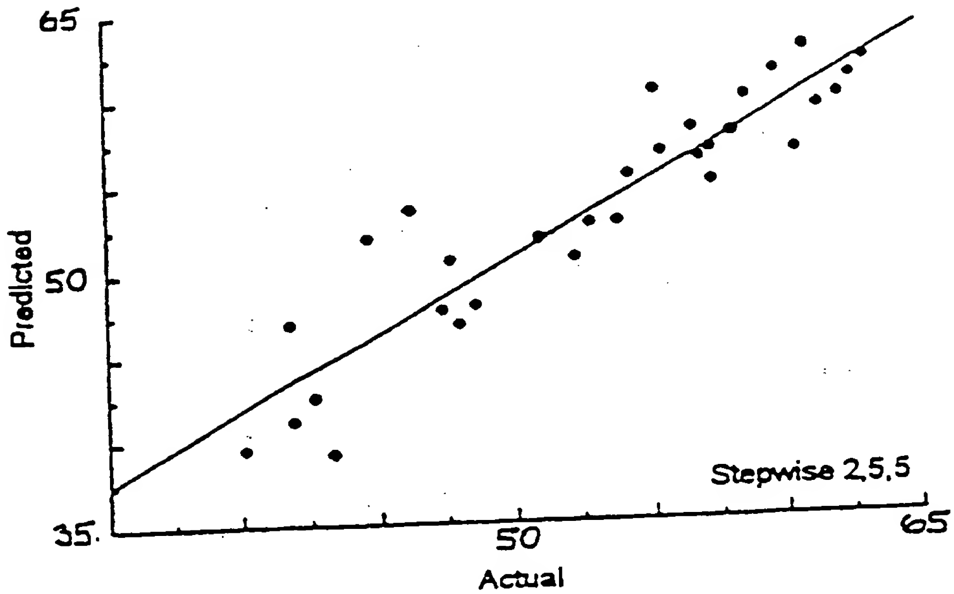

0.00020
0.00015
0.00010
0.00005
0.00000
-0.00005
-0.00010
-0.00015
-0.00020
2d log 1/R
1000
1200
1400
1600
1800
2000
2200
2400
2600
Wavelength (nm)

Figure 2a

Digestibility of dry matter *in vitro* (%)



Energy required to compress (kJ/kg DM)

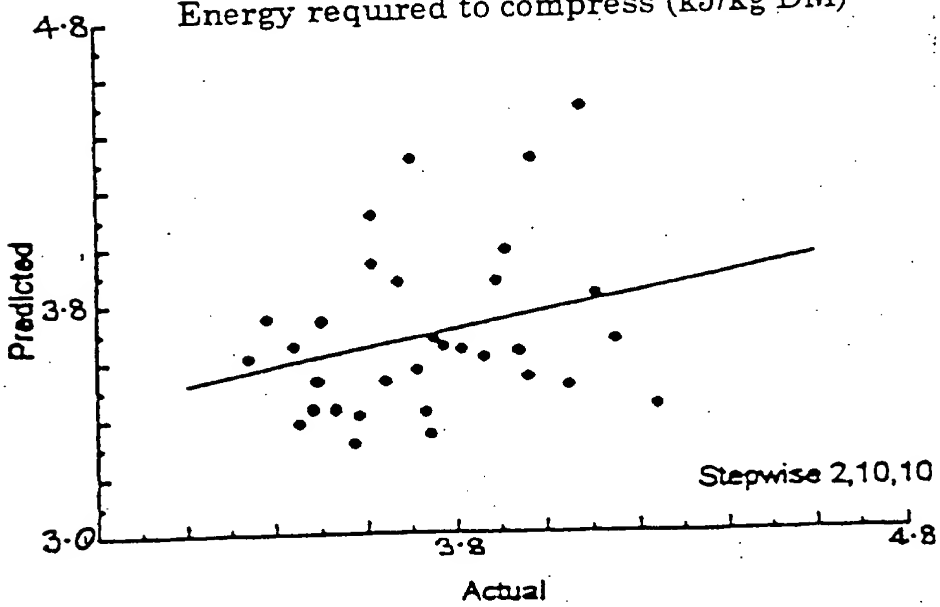
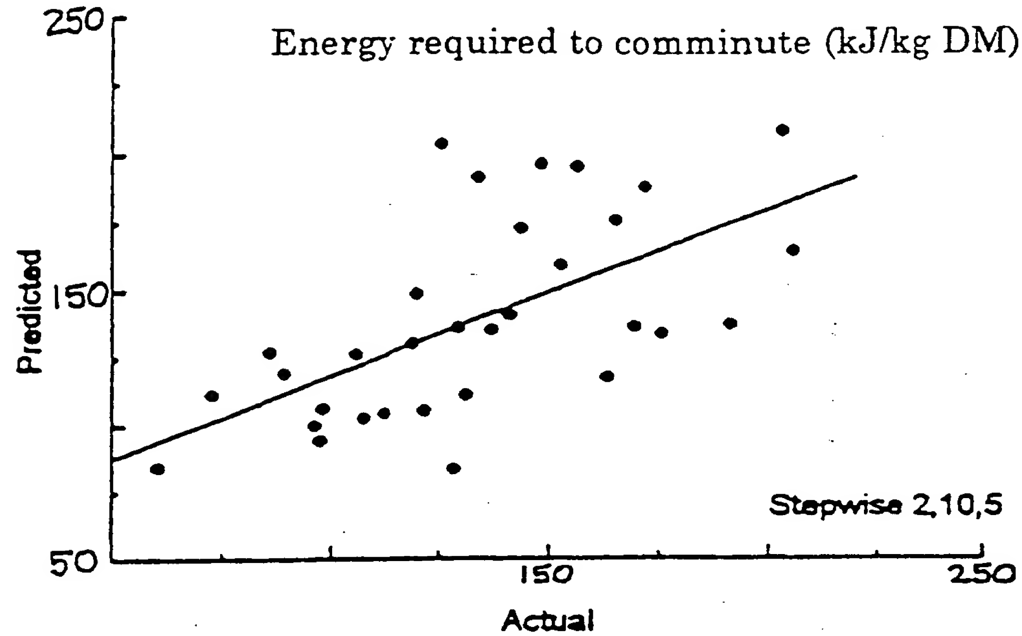


Figure 2a (cont'd)



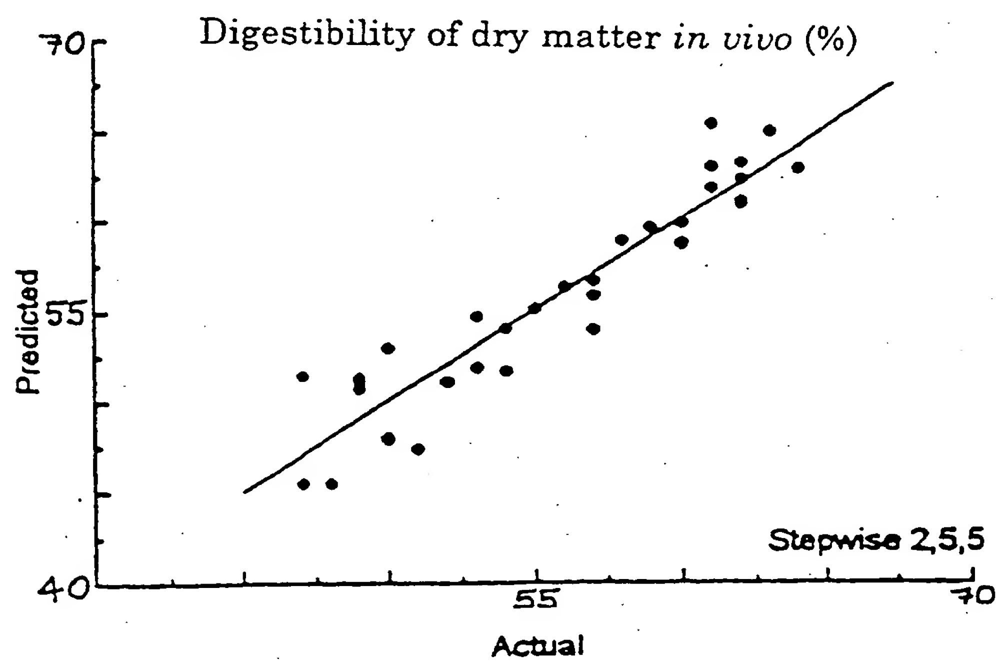


Figure 2a (cont'd)

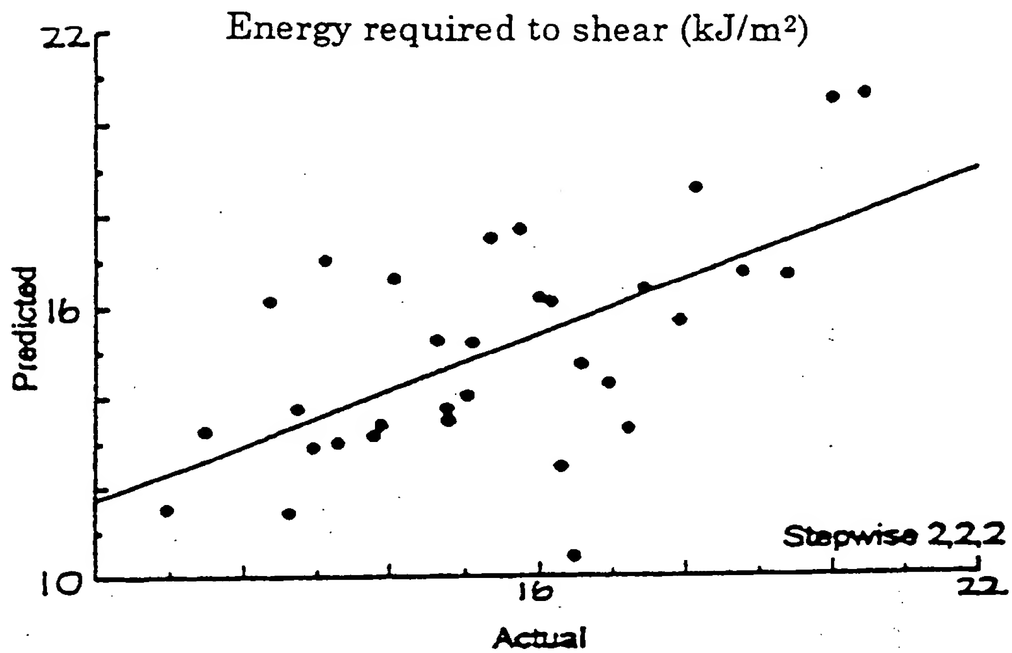
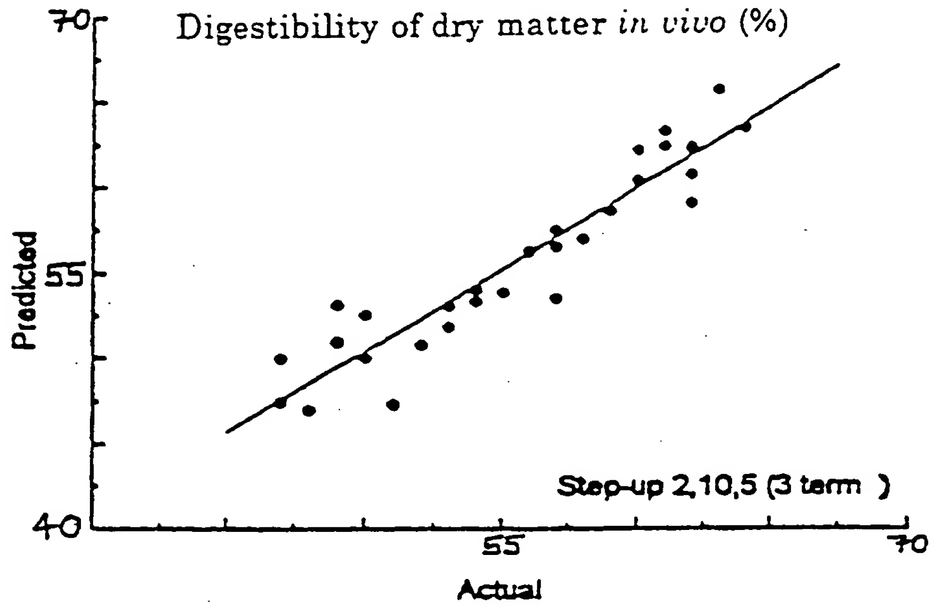


Figure 2b


Digestibility of dry matter *in vivo* (%)
70
55
40
Predicted
55
70
Actual
Step-up 2,10,5 (3 term)

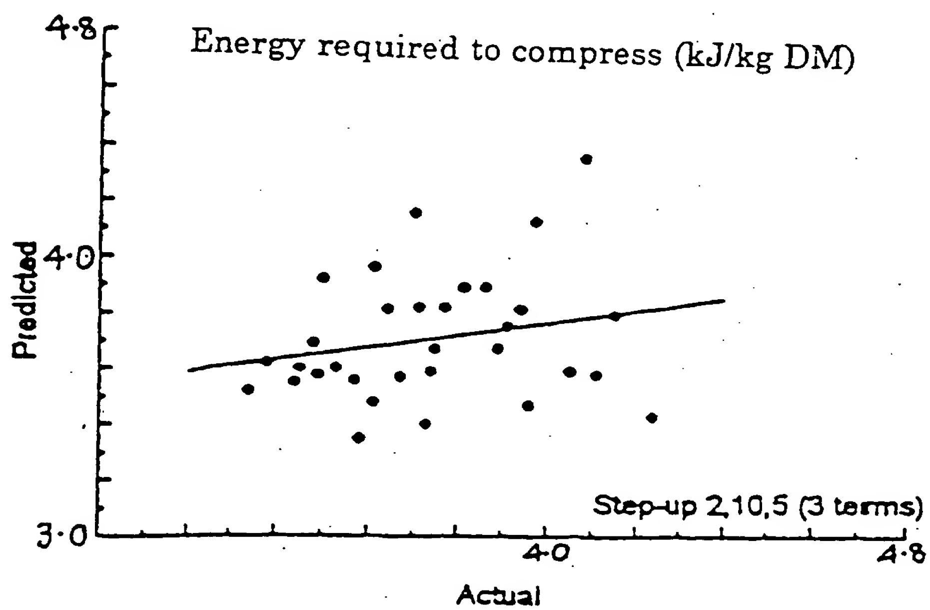
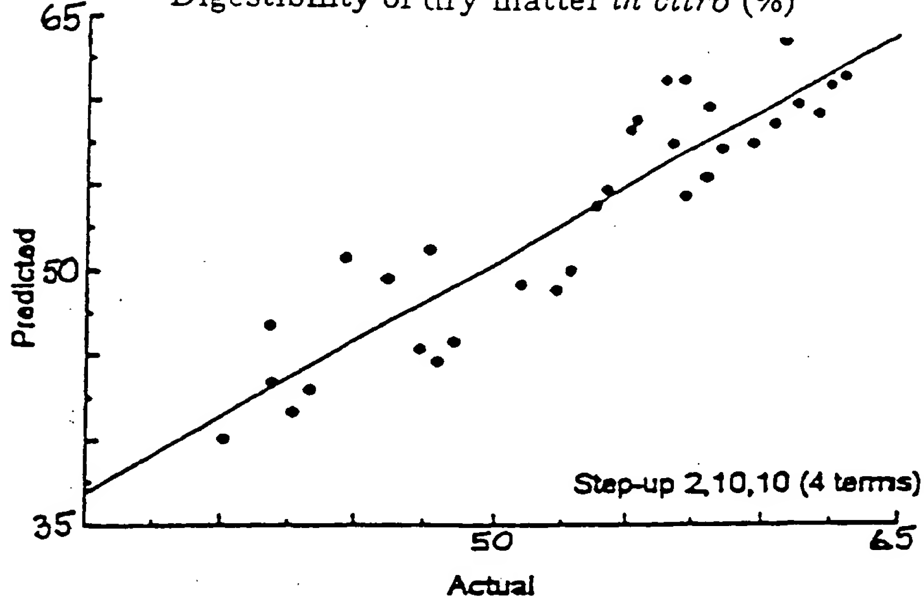

Energy required to compress (kJ/kg DM)
4·8
4·0
3·0
Predicted
4·0
4·8
Actual
Step-up 2,10,5 (3 terms)

Figure 2b (cont'd)

Digestibility of dry matter *in vitro* (%)



Energy required to shear (kJ/m^2)

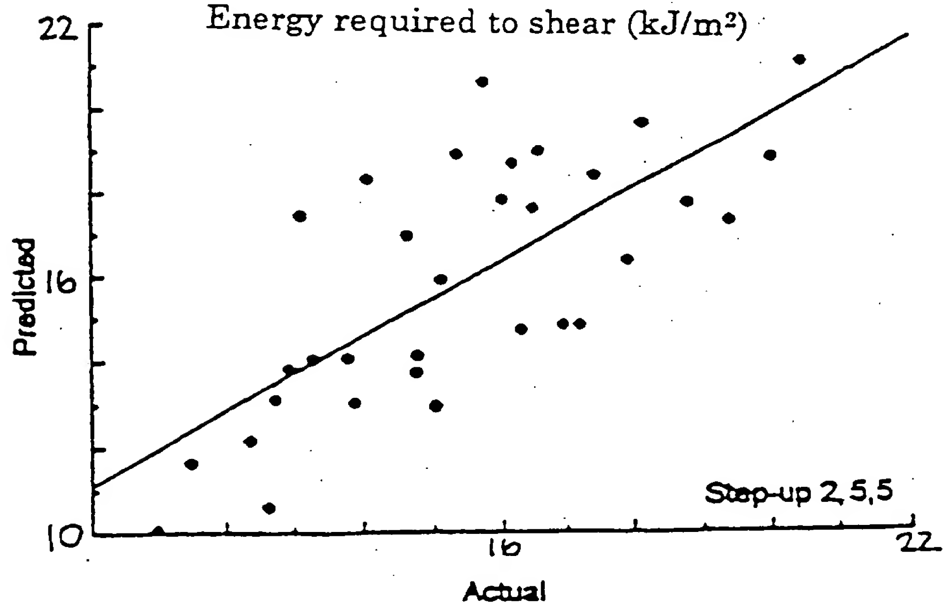


Figure 2b (cont'd)

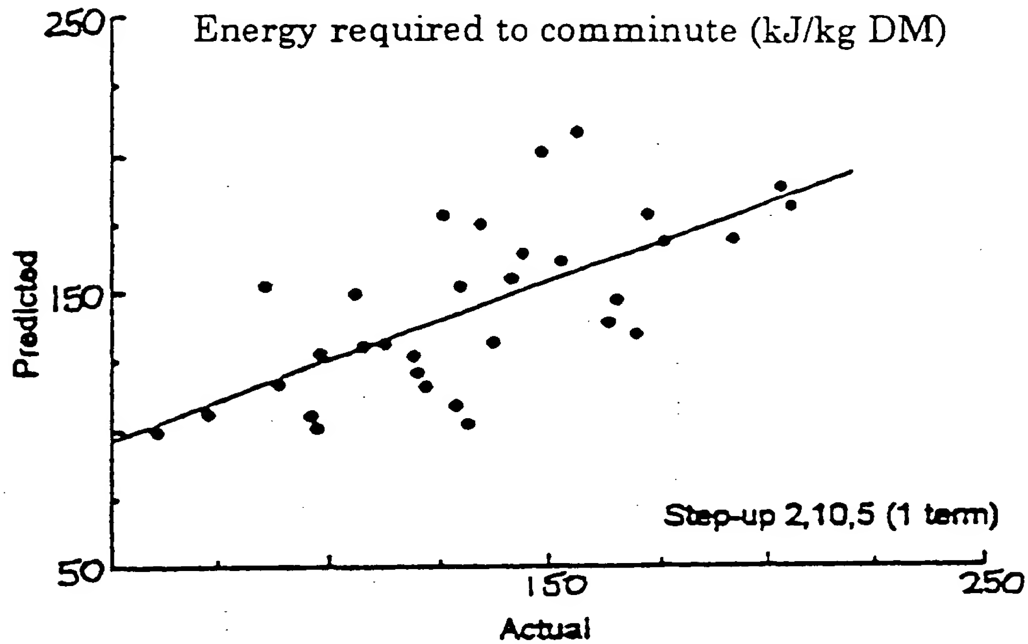
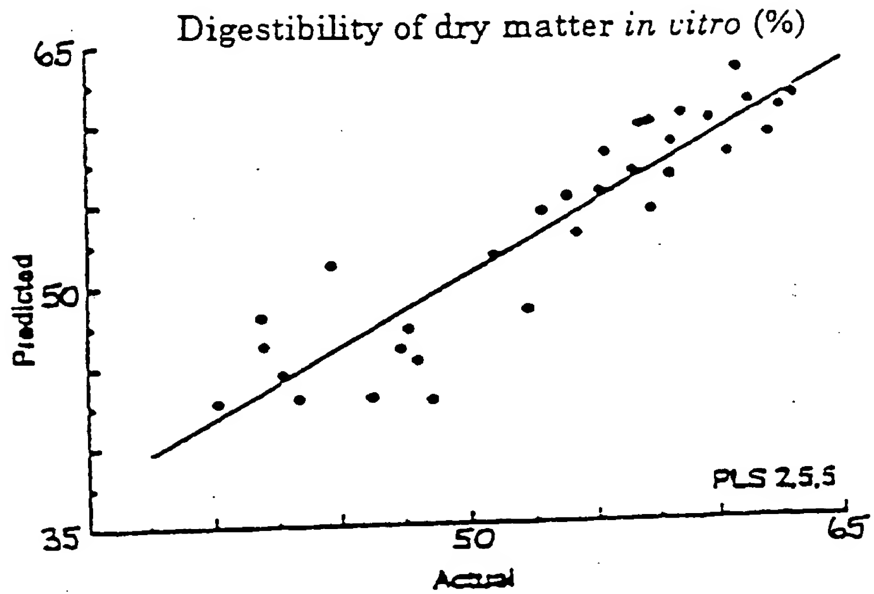


Figure 2c


Digestibility of dry matter *in vitro* (%)
65
50
35
Predicted
PLS 2,5,5
50
65
Actual

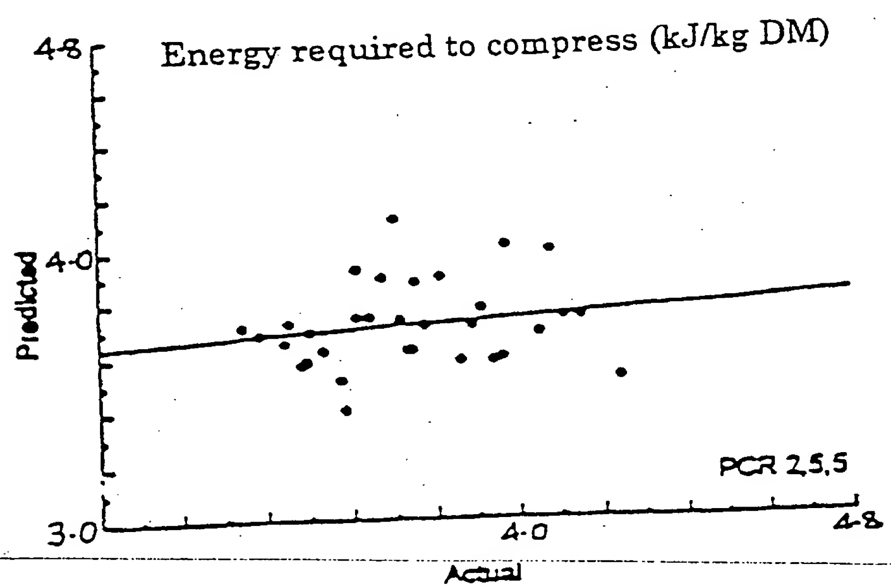
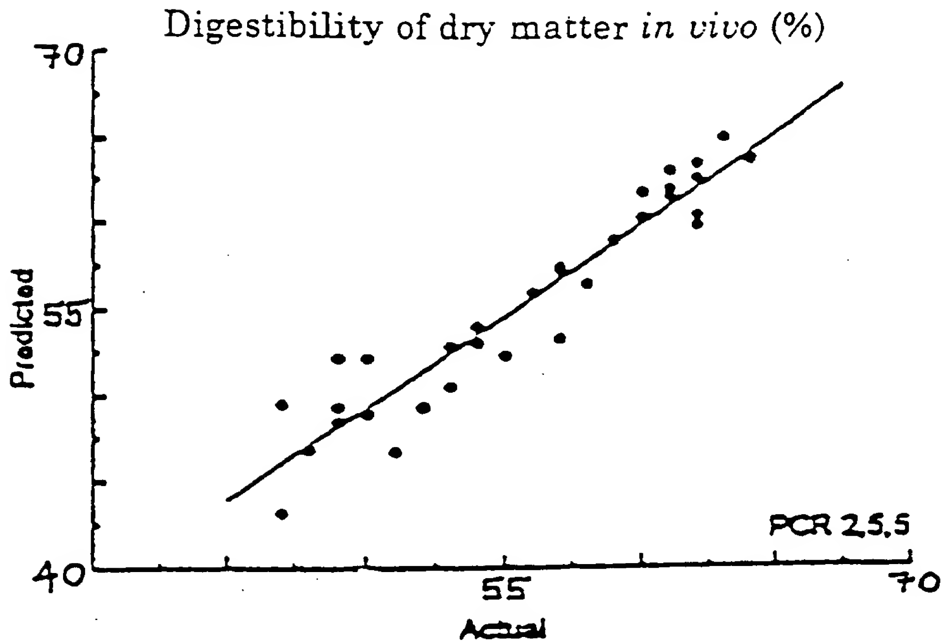

Energy required to compress (kJ/kg DM)
4·8
4·0
3·0
Predicted
PCR 2,5,5
4·0
4·8
Actual

Figure 2c (cont'd)



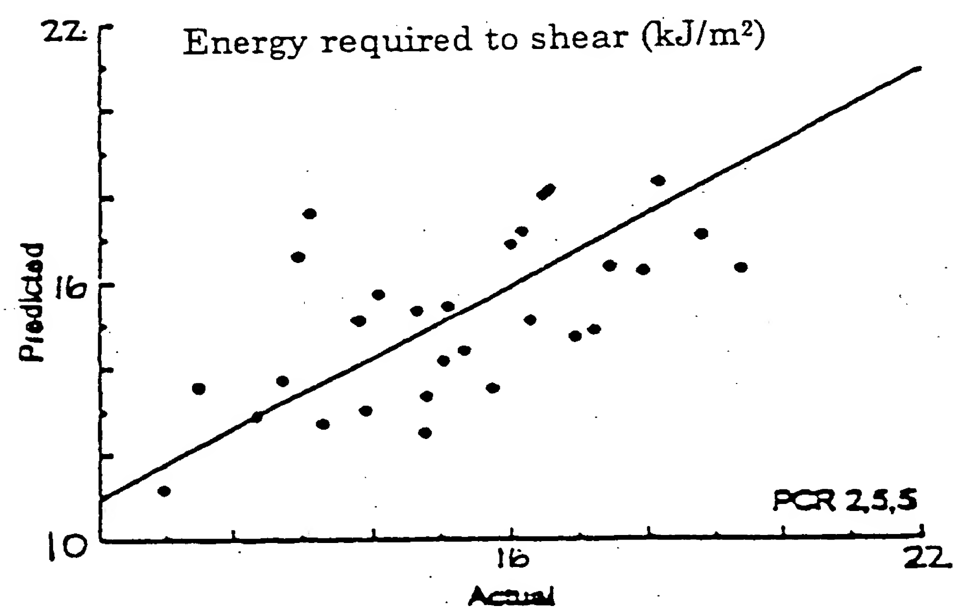


Figure 2c (cont'd)

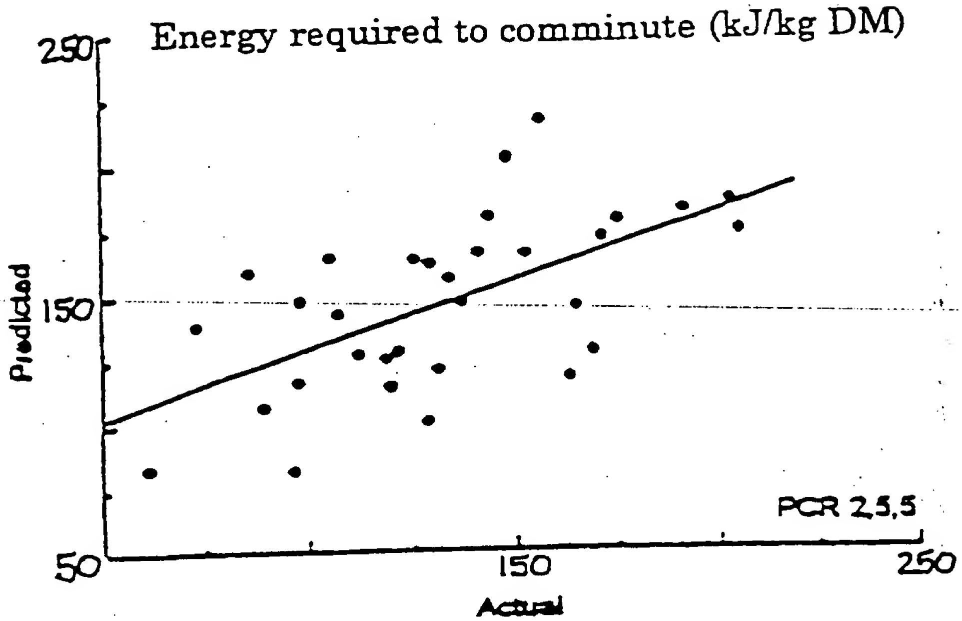
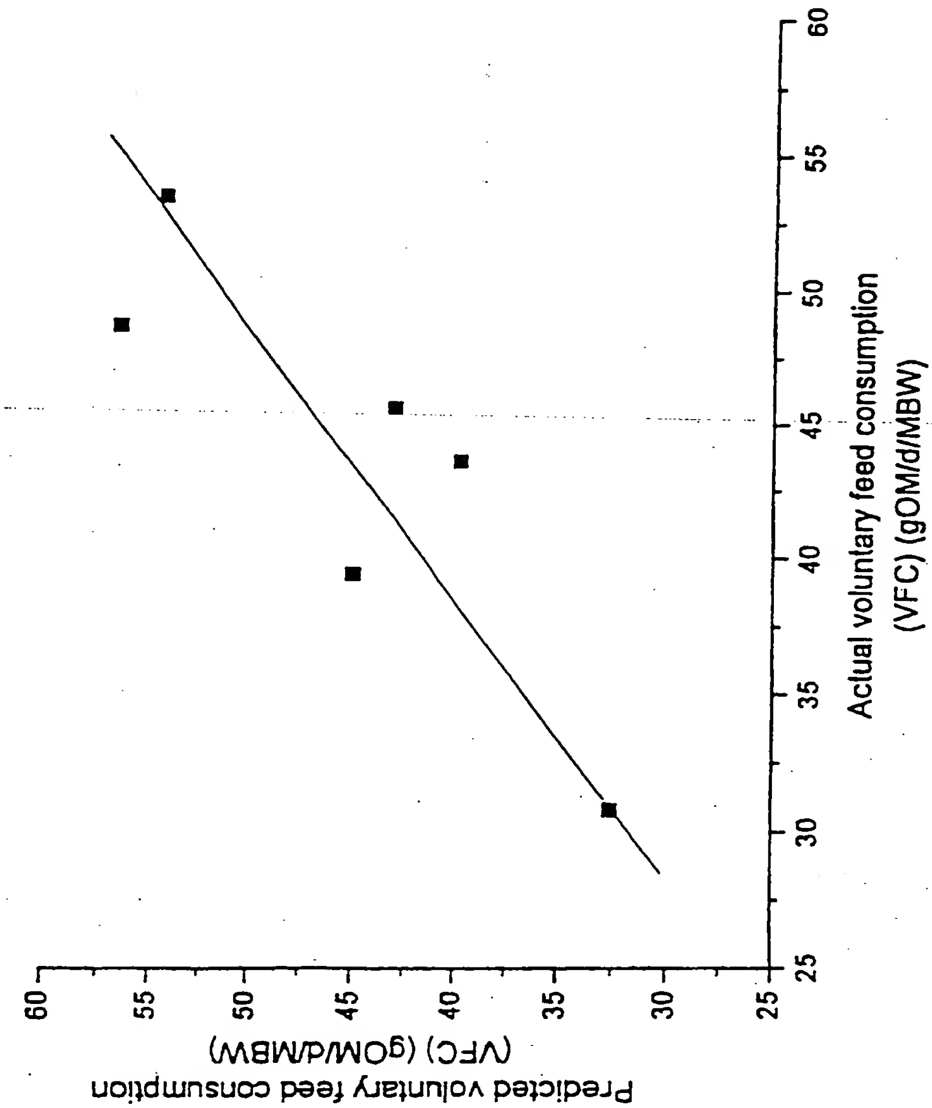


Figure 3


Predicted voluntary feed consumption
(VFC) (gOM/d/MBW)
60
55
50
45
40
35
30
25
Actual voluntary feed consumption
(VFC) (gOM/d/MBW)
25
30
35
40
45
50
55
60

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 96/00776

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl[6]: G01N 21/35, G01J 3/42

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: G01N 21/34, 21/35, 33/02, G01J 3/28, 3/42

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU:IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT, JAPIO: (IR or infrared or infra()red), (bond: or energ:)
DIALOG: "Science" Supergroup:[(IR or infrared or infra()red) and (bond? or energ?) and spectr? and (feed or fodder or hay)]

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Animal Feed Science and Technology, Vol. 37 No. 3-4, 1992 Elsevier Science Publishers B.V., Amsterdam, "Influence of growth type and season on the prediction of the metabolisable energy content of herbage by near-infrared reflectance spectroscopy", pages 281-295 by D.I. GIVENS et al. See entire document	1-28
X	Animal Feed Science and Technology, Vol. 51, February 1995, Elsevier Science B.V., "The use of NIRS to predict the chemical composition and the energy value of compound feeds for cattle", pages 243-253 by J.L. de BOEUER et al. See entire document	1-28

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 26 February 1997	Date of mailing of the international search report 06.03.97
Name and mailing address of the ISA/AU AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No.: (06) 285 3929	Authorized officer **GREG POWELL** Telephone No.: (06) 283 2308

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 96/00776

C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Proceedings 9th European Poultry Conference, Glasgow, UK, 7-12 August 1994: Volume 2. Symposia papers, published by WPSA, UK. "Current status of near infrared (NIR) spectroscopy in Australia for predicting metabolisable energy of poultry feeds", pages 106-109 by P.C. FLINN et al. See entire document	1-28
X	Agri-Practice, Vol. 12, No. 3, May/June 1991, Veterinary Practice Pub. Co., USA, "Forage Analyses for Dietary Diagnosis and Management", pages 29-32 by B. ANDERSON et al. See entire document	1-28
X	Bulgarian Journal of Agricultural Science, Vol. 1, No. 1, 1995, Agricultural Academy of Bulgaria, "Estimation of Composition, Digestibility and Feeding Value of Forages by Near Infrared Reflectance Spectroscopy. II. Estimation of Energy Value and Protein Value of Forages" pages 35-44 by S.L. ATANASSOVA et al. See entire document	1-28
P,A	WO 96/24843 A (WOLFKING DANMARK A/S) 15 August 1996 See page 9, lines 22-24 See page 11 line18 - page 14 line 6 See page 16 line 28 - page 17 line 22 See page 18 line 13 - page 20 line 21 See Examples	1-28
A	Derwent Abstract Accession No. 93-180660/22, Class S03, SU 1739284 A1 (UNIV DNEPR) 7 June 1992 See abstract	
A	Proceedings of the XVII International Grassland Congress 1993, "Genotypes of dry matured subterranean clover differ in shear energy", pages 592-593 by S.K. BAKER et al. See entire document	
A	Proceedings of the XVII International Grassland congress 1993, "Composition of the fractions of dry mature subterranean clover digested *in vivo* and *in vitro*" pages 593-595 by L. KLEIN et al. See entire document	
A	Patent Abstracts of Japan, E-78, page 1060, JP 53-15890 A (SHIMAZU SEISAKUSHO K.K.) 14 February 1978 See abstract	
A	Patent Abstracts of Japan, JP 06-123700 A (HAMAMATSU PHOTONICS KK) 6 May 1994 See abstract	
A	Patent Abstracts of Japan, P-393, page 58, JP 60-98335 A (KOGYO GIJUTSUIN (JAPAN)) 1 June 1985 See abstract	

INTERNATIONAL SEARCH REPORT	International Application No.
Information on patent family members	PCT/AU 96/00776

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	9624843	AU	A1 46193/96	AU	A1 46194/96	AU	A1 46195/96
		DK	A 155/95	DK	A 90/96	DK	A 91/96

END OF ANNEX